MISSOURI RIVER

DESIGN STUDY

MRD HYDRAULIC LABORATORY SERIES
REPORT NO. 4

LABORATORY INVESTIGATION
OF
MANAWA AND BELLEVUE BENDS

MEAD HYDRAULIC LABORATORY
MEAD, NEBRASKA

U. S. ARMY ENGINEER DISTRICT, OMAHA
U. S. ARMY ENGINEER DISTRICT, KANSAS CITY
MISSOURI RIVER DIVISION, OMAHA

FEBRUARY 1972

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
February 1972

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Laboratory Investigation of Marawa and Bellevue Bends

5. FUNDING NUMBERS

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Mead Hydraulic Laboratory
Mead, NE

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Omaha District, Corps of Engineers
215 N. 17th St.
Omaha, NE 68102

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
MRD Hydraulic Laboratory Series No. 4

11. SUPPLEMENTARY NOTES
U.S. Army Engineer District, Kansas City, MO
Missouri River Division

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This report has been approved for public release and sale; its distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes the results of a model study of Manawa and Bellevue Bends of the Missouri River. The study was conducted at the Mead Hydraulic Laboratory by personnel of the Hydro-Sediment and Channel Stabilization Sections of the Omaha District, Corps of Engineers under the general supervision of the Missouri River Division.

Attempts to control the Missouri River have been in progress for many years. Various arrangements of dikes, sills, and revetments have been constructed to control the overall river alignment and to insure a suitable navigation channel. The overall channel alignment of the Missouri River between Sioux City, IA and the mouth has in general been established with the shape of each major been controlled by a combination of spur dikes and bank revetment. One of the most severe problems is maintaining an adequate navigation channel width through a sharp bend.

14. SUBJECT TERMS
river bends
Missouri River
navigation channels

15. NUMBER OF PAGES
17

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

Laboratory Investigation of Manawa and Bellevue Bends
Conducted at
MEAD HYDRAULIC LABORATORY
MEAD, NEBRASKA

U. S. ARMY ENGINEER DISTRICT, OMAHA, NEBRASKA
U. S. ARMY ENGINEER DISTRICT, KANSAS CITY, MISSOURI
MISSOURI RIVER DIVISION, OMAHA, NEBRASKA

February 1972

TABLE OF CONTENTS

REFERENCES

1. U. S. Army Corps of Engineers, Missouri River Division. "Operation and Function of the Mead Hydraulic Laboratory", MRD Hydraulic Laboratory Series Report No. 1, March 1969.

2. U. S. Army Corps of Engineers, Missouri River Division, "Laboratory Investigation of Underwater Sills on the Convex Bank of Pomeroy Bend", MRD Hydraulic Laboratory Series Report No. 2.

MANAWA - BELLEVUE MODEL STUDY

(LIST OF FIGURES & PLATES)

LABORATORY INVESTIGATION OF MANAWA AND BELLEVUE BENDS

INTRODUCTION

1. This report describes the results of a model study of Manawa and Bellevue Bends of the Missouri River. The study was conducted at the Mead Hydraulic Laboratory by personnel of the Hydro-Sediment and Channel Stabilization Sections of the Omaha District, Corps of Engineers under the general supervision of the Missouri River Division.

2. Attempts to control the Missouri River have been in progress for many years. Various arrangements of dikes, sills, and revetments have been constructed to control the overall river alignment and to insure a suitable navigation channel. The overall channel alignment of the Missouri River between Sioux City, Iowa, and the mouth has in general been established with the shape of each major bend controlled by a combination of spur dikes and bank revetment. However, within this general alignment, problems in maintaining an adequate navigation channel still exist at various locations. One of the most severe problems is maintaining an adequate navigation channel width through a sharp bend.

DESCRIPTION OF MANAWA AND BELLEVUE BENDS

3. Manawa and Bellevue Bends are located about ten miles south of Omaha, Nebraska and extend from Missouri River mile 601 to 608. The concave (outer) banks of both bends are almost completely controlled with rock revetment. The lower portion of Bellevue Bend is controlled by a series of "L" shaped structures covering approximately seventy-five percent of the concave bank. Indian Creek and Mosquito Creek enter the Missouri River in Manawa Bend at mile 608 and 605.8 respectively.

4. The convex banks, or inside of the bends, are controlled by a series of spur dikes spaced intermittently throughout the bends. The distance between these dikes progressively increases throughout each bend and at normal navigation flows, the structures extend above the water surface. Figure 1 shows the general river alignment in the vicinity of Manawa and Bellevue Bends, and Plate 1 shows the control structures in the study reach as of October 1966. The degree of curvature in Manawa Bend progressively increases in the downstream direction creating a deep narrow channel concentrated along the outside of the bend. At the lower end of Manawa Bend, a short crossing directs the flow to the right bank of Bellevue Bend where the curvature reverses. This bend also is characterized by a deep narrow channel.

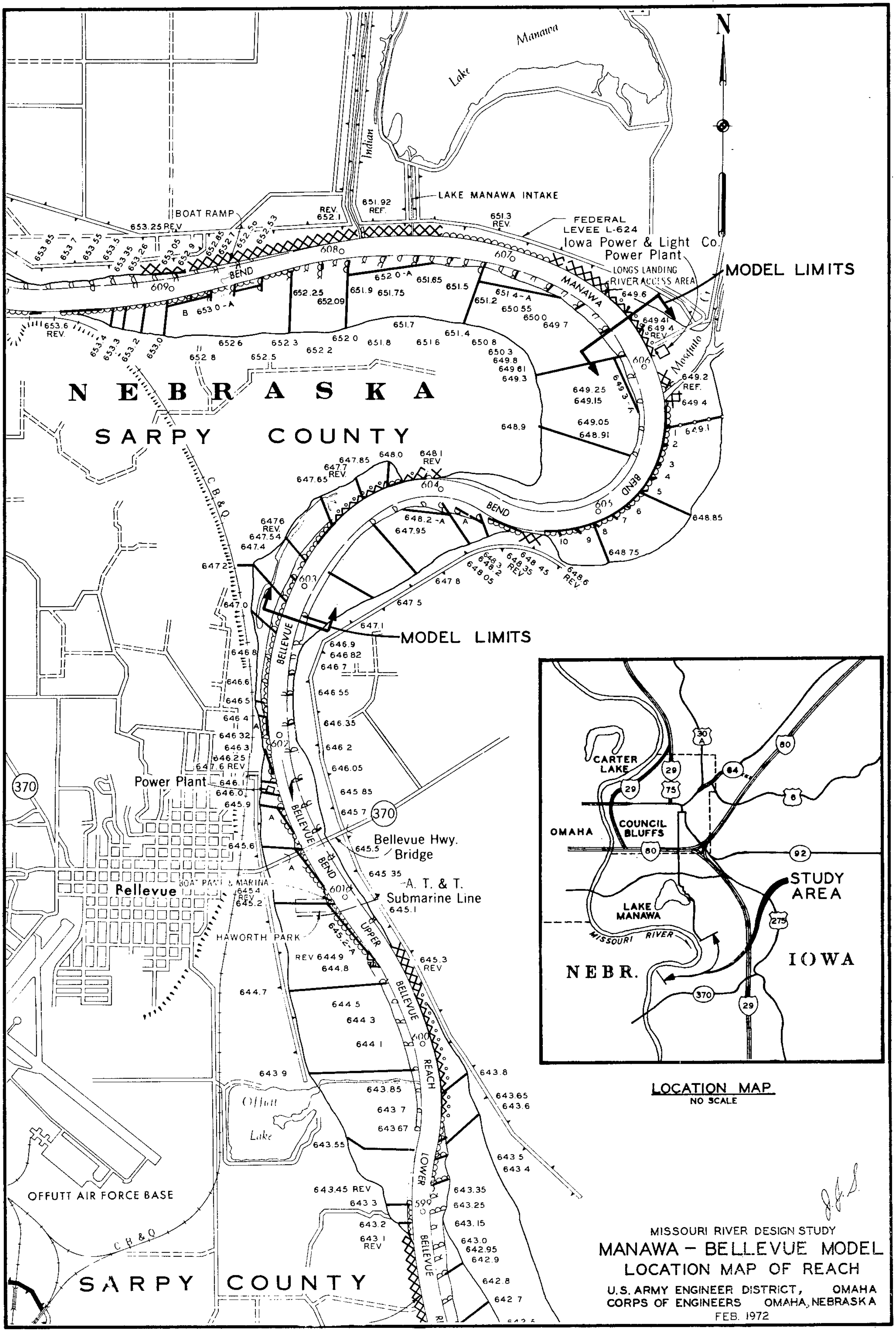

N
Lake Manawa
Indian
LAKE MANAWA INTAKE
BOAT RAMP
FEDERAL LEVEE L-624
Iowa Power & Light Co. Power Plant
LONGS LANDING RIVER ACCESS AREA
MODEL LIMITS
MANAWA BEND
Mosquito
NEBRASKA
SARPY COUNTY
C B & Q
MODEL LIMITS
BELLEVUE BEND
Power Plant
Bellevue Hwy. Bridge
A. T. & T. Submarine Line
BOAT PARK & MARINA
Bellevue
HAWORTH PARK
UPPER BELLEVUE REACH
LOWER BELLEVUE REACH
Offutt Lake
OFFUTT AIR FORCE BASE
SARPY COUNTY
CARTER LAKE
OMAHA
COUNCIL BLUFFS
LAKE MANAWA
MISSOURI RIVER
STUDY AREA
NEBR.
IOWA
LOCATION MAP
NO SCALE
MISSOURI RIVER DESIGN STUDY
MANAWA – BELLEVUE MODEL
LOCATION MAP OF REACH
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
FEB. 1972

Figure 1

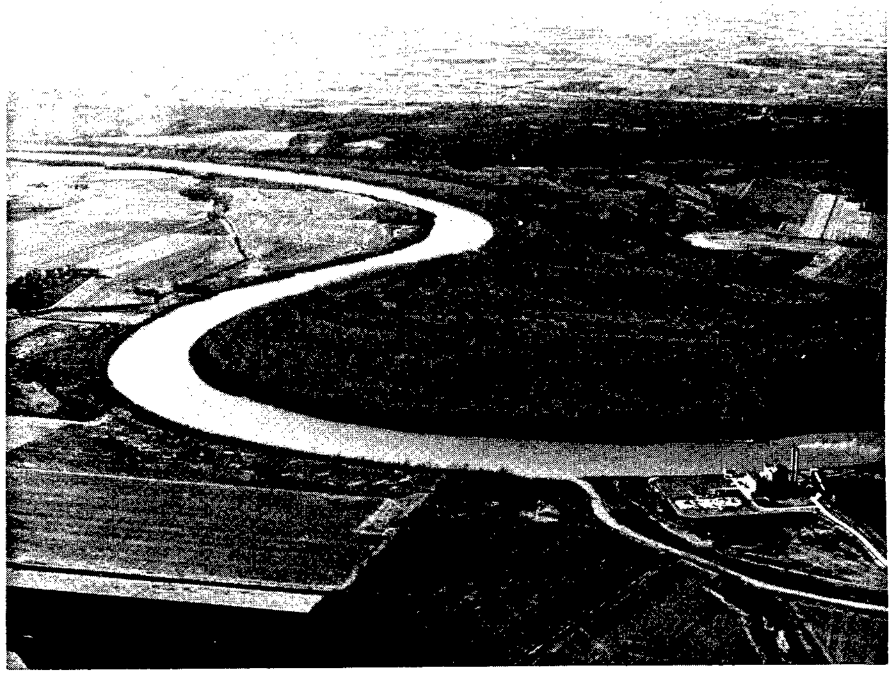


Figure 2 - Photograph of Manawa and Bellevue Bends
Looking Downstream

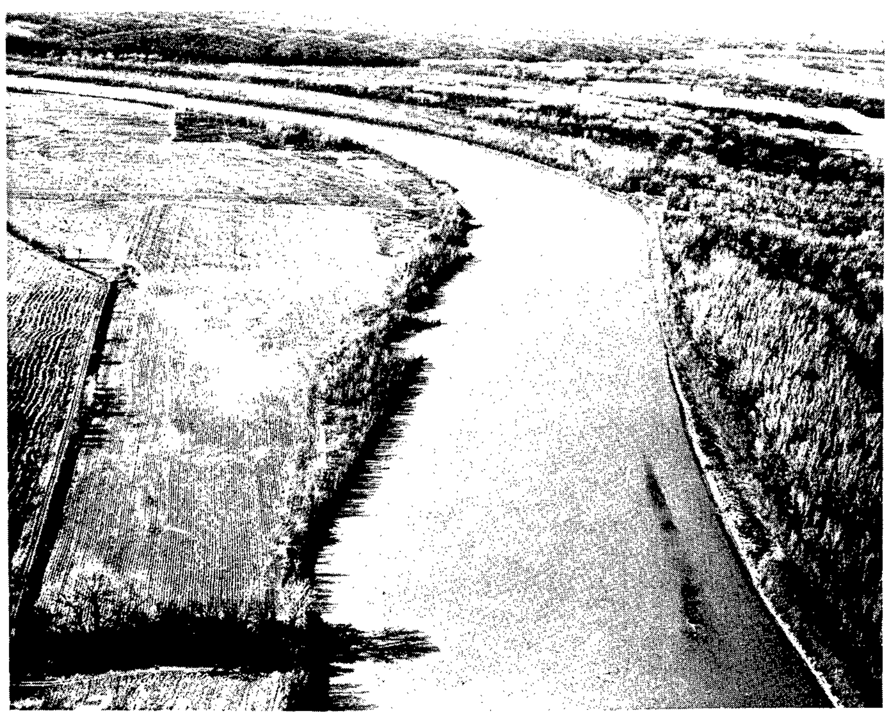


Figure 3 - Photograph of the Crossing Looking
Downstream.

PURPOSE OF STUDY

5. Specific design criteria for developing an adequate navigation channel width thru sharp bends is limited. To date, no completely effective system of structures has been developed that will insure a desired set of channel dimensions. There are systems of structures that assist in the development of such a channel; however, their exact shape, extent of construction, or effectiveness is not easily predetermined. This model study concentrated on developing a system of structures specifically for the Manawa - Bellevue reach of the Missouri River. The objectives were as follows.

1. Develop a wider, more uniform channel in the lower portion of Manawa Bend.

2. Improve the short abrupt crossing between Manawa and Bellevue Bends.

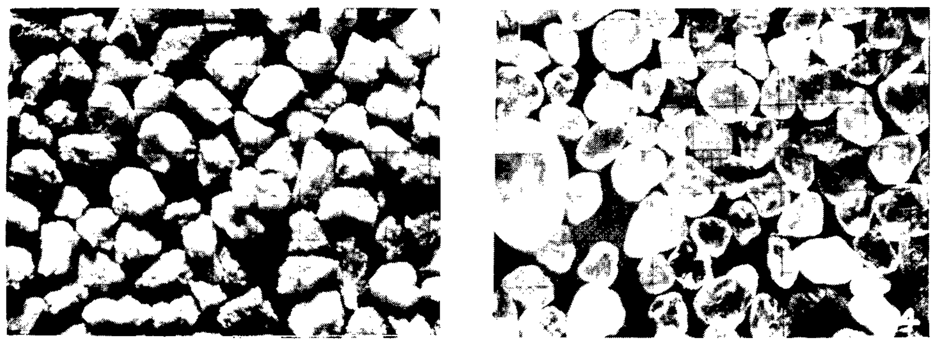
3. Increase the width of the navigation channel in upper Bellevue Bend.

MODEL DESIGN AND VERIFICATION

6. The bed material for this model, like in previously completed studies at the Mead Hydraulic Laboratory,[1] was finely ground walnut shells. The gradation and particle shape is similar to the sand found in the bed of the Missouri River. This material responds very much like sand, but has a specific gravity of only 1.33 compared to 2.65 for sand. Use of this light-weight bed material permitted the model to be operated at low velocities and still maintain a relatively high sediment transport rate both as bed and suspended load. The high transport rate provided a desirable time-scale ratio. Figures 4 and 5 illustrate the size and shape similarities between the ground walnut shells and Missouri River sand.

7. Verification of a river model involves the determination of a set of parameters by which the model will act and react to changes much in the same manner as in the prototype. The length of the study reach and the corresponding horizontal scale was determined by selecting the largest model that could be fitted within the physical limits of the building. The vertical scale, or depth dimension, and the velocity scale were determined by a series of verification runs.

8. One method of determining the depth and velocity scales for hydraulic models is to keep the Froude ratio equal to unity. The use of this relationship permits the computation of either the depth or velocity scale ratio after a value for the other variable has been selected. However, in a movable bed model, an additional variable is



Walnut Shells Missouri River Sand

Figure 4 - Photomicrograph of Test Materials, Grid Size: 0.39 mm.

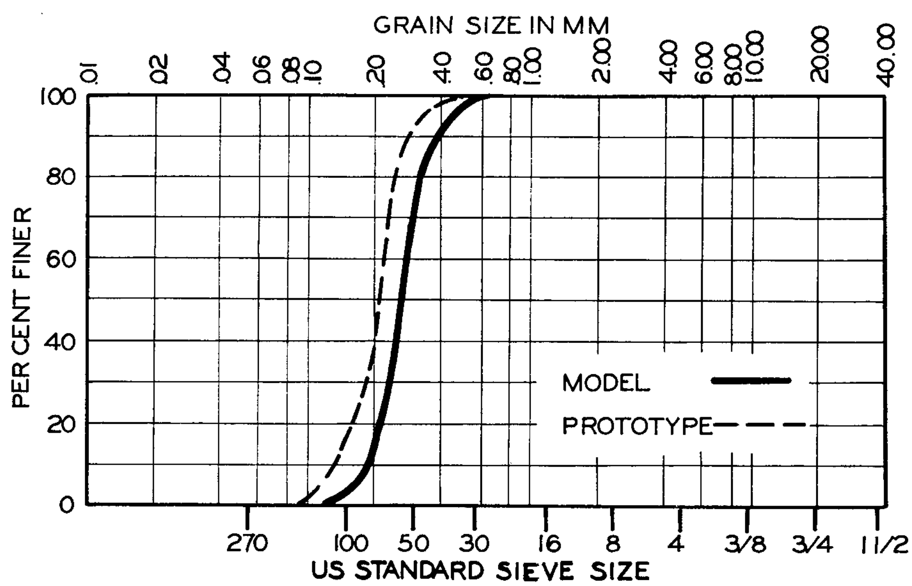


Figure 5 - Size Distribution Curves of Bed Materials

present which is not represented in the Froude Number. This is the rate of sediment movement both in suspension and along the bed. The method by which sediment moves and deposits is not only a function of depth and velocity, but is also dependent upon such things as the characteristics of the bed material, bottom roughness, intensity of turbulence, and the width depth ratio of the stream. Physical limitations of the model did not permit the same depth and length ratio because the resulting model depth would be too shallow for accurate vertical measurements. The required vertical to horizontal distortion, in addition to influencing the above factors, also influences the shape of the bed formations.

9. Preliminary tests revealed that the model would not reproduce the prototype if the Froude ratio was unity. Prototype measurements indicated high concentrations of flow along the concave banks of both Manawa and Bellevue Bends. It was, therefore, imperative that these conditions also exist in the model. To assist in the selection of the depth and velocity scales, a series of tests were conducted in which both of these scales were varied. This permitted observation of the bed forms and channel characteristics under a range of model conditions. The discharge distribution, velocity distribution, and channel geometry were observed for each of these tests. A comparison of these factors for both model and prototype is presented on Plate 2. A satisfactory reproduction is evident.

10. Using the results of the verification tests as a guide, a complete set of model scales was established. Because of the infrequent fluctuations in the discharge of the Missouri during the navigation season, the average discharge during that period was selected as the basic discharge for the model study. No attempt was made to reproduce a seasonal runoff hydrograph, as a new set of scale relationships would be necessary for each discharge involved. The final scale relationships which were adopted for the study are listed in Table I.

TABLE I

SCALE RATIOS

	Missouri River Manawa-Bellevue Bends	Model Run 17*	Scale Ratio Prototype/Model
Discharge, cfs	31,500	0.956	33,000
Average Depth, ft	10.6	0.302	35
Channel Width, ft	700	5.81	120
Average Velocity, fps	4.25	0.545	7.80
Slope, ft/ft x 10^4	1.45	5.30	0.27
Manning's "n"	.020	.028	0.71
Specific Gravity of Bed Material	2.65	1.33	2.00
D35	0.18	0.23	0.78
D50	0.21	0.26	0.81
D65	0.23	0.30	0.77
Froude No.	0.230	0.175	1.31

* Model Test No. 17 was used to compute these ratios since it best reproduced the prototype channel geometry and flow distributions.

TEST PROCEDURE

11. The model basin was a completely closed system which recirculated both the water and the transported sediment. (1) The water depth in the model was controlled by regulating the volume of water in the system. No tailgate or depth control structure of any kind was used; therefore, the water surface and bed slopes were free to adjust themselves to the conditions imposed upon them. At the beginning of a given test, a large amount of bed material was shifted throughout the system. However, after the model had been in operation for a period time, an equilibrium condition was achieved where the suspended sediment and bed forms were still in movement, but drastic changes in the channel configuration were no longer occurring. Two methods were used to establish when these conditions had been achieved. The first was by monitoring the water surface slope. At the beginning of a test, the water surface slope would change rapidly, but as time progressed, it would tend to stabilize around some constant value. The slope was determined by measuring the energy grade elevation thru the use of impact tubes spaced approximately ten feet apart in the flume. These were connected by small plastic tubing to a bank of stilling wells from which very accurate measurements were possible. One set of these measurements is shown in Figure 6. The impact tubes measure the static head plus the velocity head at the tubes; however, the velocities are very low and the measured energy grade line was assumed to be equal to the water surface elevation.

12. The second method used to determine when equilibrium existed was by monitoring the sediment transport rate thru the system. The sediment load was observed to change rapidly at the beginning of a test, and would ultimately stabilize at some constant value. (1)

13. At the completion of each test, the basin was flooded and channel cross-sections surveyed with a sonic depth sounding apparatus. This instrument gives a true reproduction of the bed formations on a continuous X - Y plot, from which the hydraulic characteristics and channel dimensions were determined. A sample of the data obtained in this manner is shown on figure 7.

14. Use of the recirculating basin did not permit one to accurately determine the average water depth until the completion of a model test. (2) One method of approximating the proper water depth was to control the water surface elevation at some point near the center of the flume and allow the slope to vary around this point. The actual average depth for a test was not known until the run was completed and the final cross-sections measured. It would have been desirable to maintain a constant depth for all tests, however, small differences did exist. These differences were usually less than two percent, and no corrections were found necessary.

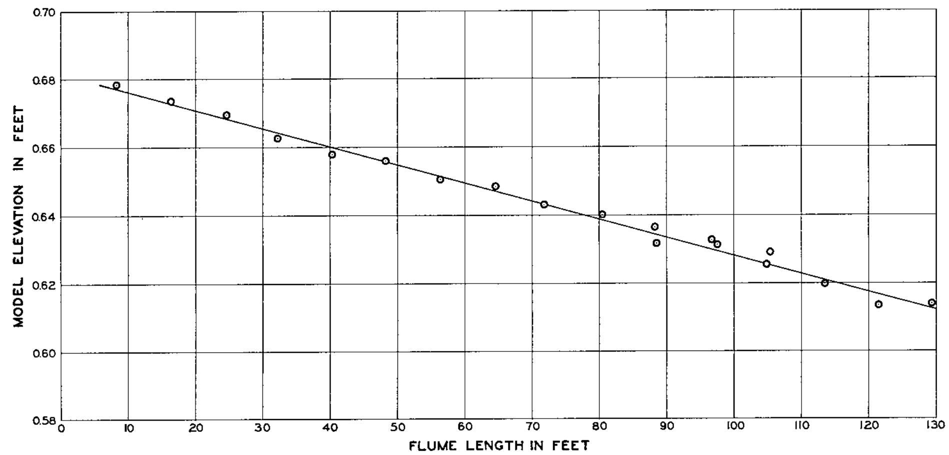


Figure 6. Typical Energy Profile observed at the completion of model verification test Number 17.

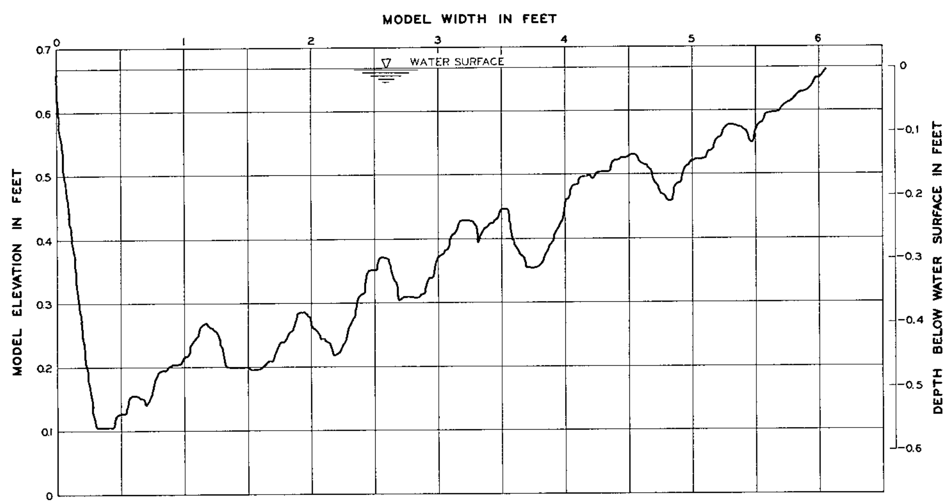


Figure 7. Model cross-section plotted by Depth Sounding Apparatus. Cross-section plotted during verification test Number 17 at Mile 605.6 Section taken looking downstream.

DATA ANALYSIS

15. Table two is a summary of the measured data and the hydraulic computations for each test. The basic quantities; discharge, average depth, energy slope, and sediment concentration are average values of measurements taken during or after a test. The remaining items are functions of these basic quantities and can be used to compare one run with another. The ability of a given arrangement of structures to develop the desired navigation channel dimensions indicates the effectiveness of the system. Since the tests were operated basically at the same depth and discharge, changes in the bed formations or hydraulic functions were assumed to be the result of changes in the structure configuration. A description of each of the items shown in Table 2 is as follows:

Column (1)	Model test number.
Column (2)	The discharge in cfs used for the test.
Column (3)	The average flow area of the measured cross sections. Generally more than 20 sections were used to establish this average.
Column (4)	The average of the mean depth for each cross section, computed by dividing the area by the top width. The hydraulic radius was assumed to be equal to this value.
Column (5)	The average velocity determined by dividing the discharge by the average cross sectional area.
Column (6)	The slope of the energy grade line near the completion of each test.
Column (7)	The suspended sediment concentration in parts per million. These are average values of samples collected after the model had reached an equilibrium.
Column (9)	The Froude No. $F = \frac{V}{\sqrt{gd}}$ represents the ratio of inertia forces to the gravitational force as they existed in the model.
Column (8)	Manning's "n" - Composite roughness computed by: $n = \frac{(1.486)\ (A)\ (R^{2/3})\ (S^{1/2})}{Q}$ Where A = Average Area; R = Hydraulic radius = Average depth; S = Energy Slope; Q = Discharge

DESCRIPTION OF MODEL TESTS AND TEST RESULTS

16. The model tests were divided into three separate parts. Attempts were made to widen the channel in Manawa Bend; improve the short abrupt crossing between Manawa and Bellevue Bends; and increase the width of the navigation channel in Bellevue Bend. Each of these are discussed separately. All length and depth dimensions presented in this report represent prototype values.

TABLE 2

SUMMARY OF HYDRAULIC COMPUTATIONS

Run Number		Discharge (cfs)	Cross Sectional Area (ft^2)	Ave. Depth (ft)	Ave. Velocity (ft/sec)	Water Surface Slope (FT/ft)	Sus. Sed. Con.(ppm)	Manning's "n"	Froude No.
1		0.679	1.34	0.247	0.51	6.7	550	0.030	0.179
2		0.941	1.32	0.238	0.72	8.3	1620	0.023	0.258
3		0.968	1.87	0.312	0.52	6.0	820	0.032	0.164
4		1.308	1.87	0.318	0.70	5.9	1390	0.024	0.219
5		0.981	2.12	0.404	0.41	3.2	170	0.035	0.113
6		1.394	2.34	0.390	0.60	4.4	500	0.028	0.168
7		1.613	2.26	0.381	0.71	5.0	870	0.024	0.204
8		1.200	2.63	0.439	0.46	2.4	20	0.029	0.122
9		1.500	2.78	0.465	0.54	3.0	160	0.029	0.140
10		0.400	0.72	0.123	0.55	11.6	760	0.023	0.278
11		0.502	0.73	0.128	0.69	11.5	2230	0.018	0.341
12		0.958	1.88	0.322	0.51	5.5	250	0.032	0.159
13		0.956	1.85	0.327	0.52	4.5	170	0.029	0.159
14		0.956	1.76	0.303	0.54	6.3	680	0.031	0.173
15		1.165				6.8	530		
16		1.165	1.84	0.312	0.63	6.6	1030	0.028	0.200
17		0.956	1.76	0.302	0.55	5.3	350	0.028	0.175
18	A	0.956				6.3	420		
	B	0.956				6.8	660		
	C	0.956				6.8	560		
	D	0.956				6.3	450		
	E	0.956					400		
	F	0.956				6.9	820		
	G	0.956				7.0	1500		
	H	0.956	1.64	0.278	0.58	6.2	450	0.027	0.195
	I	0.956	1.74	0.291	0.55	8.5	480	0.035	0.179
19	A	0.956	1.75	0.310	0.55	5.8	380	0.030	0.173
20	A	0.956	1.61	0.308	0.60	6.6	690	0.029	0.189
	B	0.956	1.69	0.309	0.56	7.2	560	0.032	0.179
	C	0.956	1.82	0.317	0.52	7.0	500	0.035	0.164
	D	0.956	1.74	0.310	0.57	7.4	450	0.034	0.174
	E	0.956	1.71	0.302	0.56	7.0	410	0.032	0.179
	F	0.956	1.69	0.298	0.57	6.5	540	0.030	0.183
21	A	0.956	1.58	0.276	0.61	6.9	560	0.027	0.203
	B	0.956	1.61	0.284	0.59	7.4	520	0.029	0.196
	C	0.956	1.46*	0.265	0.65	7.8	920	0.026	0.224
22	A	0.956	1.49*	0.266	0.64	6.9		0.025	0.219
	B	0.956	1.38*	0.245	0.69	7.6	610	0.023	0.247
	C	0.956	1.28*	0.232	0.75	7.3	670	0.020	0.273
23	A	0.956	1.43*	0.251	0.67	7.4	700	0.024	0.235
	B	0.956	1.41*	0.238	0.68	6.4	660	0.021	0.245
	C	0.956	1.40*	0.237	0.68	7.0	750	0.022	0.247
	D	0.956	1.43*	0.239	0.67	5.3	770	0.020	0.241
	E	0.956	1.36*	0.209	0.70	6.9	700	0.020	0.271
	F	0.956	1.28*	0.213	0.75	6.9	830	0.019	0.285
	G	0.956	1.59*	0.264	0.60	7.6	870	0.028	0.026
24	A	0.956	1.47*	0.255	0.65	5.1	720	0.021	0.227
	B	0.956	1.27*	0.251	0.75	5.8		0.019	0.265
	C	0.956	1.41*	0.259	0.68	5.3	720	0.020	0.235
	D	0.956				4.7	730		
	E	0.956				5.3	1140		
25	A	0.956	1.64	0.292	0.58	5.2	430	0.026	0.190
	B	0.956	1.62*	0.273	0.59	5.6	470	0.025	0.199
	C	0.956	1.83*	0.310	0.52	4.7	170	0.028	0.165
	D	0.956	1.86*	0.316	0.51	4.8	330	0.029	0.161
	E	0.956	1.89*	0.333	0.52	5.1	510	0.032	0.154
	F	0.956	1.67*	0.288	0.57	6.0	640	0.028	0.188
26	A	1.611				5.1			
	B	1.239				4.1			

TABLE 2 - (Cont'd)

SUMMARY OF HYDRAULIC COMPUTATIONS

Run Number		Discharge (cfs)	Cross Sectional Area (ft^2)	Ave. Depth (ft)	Ave. Velocity (ft/sec)	Water Surface Slope (FT/ft) $x10^4$	Sus. Sed. Con. (ppm)	Manning's "n"	Froude No.
27	A	0.956	1.85*	0.304	0.52	5.5	520	0.030	0.165
	B	0.956	1.80*	0.295	0.53	5.4	280	0.029	0.172
	C	0.956	1.82*	0.303	0.53	5.3	340	0.029	0.168
	D	0.956	1.84*	0.299	0.52	5.9		0.031	0.167
	E	0.956				5.6	480		
	F	0.956				5.5	370		
	G	0.956					250		
28	A	0.956				5.8	400		
29	A	0.956	2.03	0.335	0.47	5.8	660	0.037	0.143
	B	0.956				6.0			
	C	0.956							
	D	0.956							
30	A	0.956				6.1	330		
	B	0.956				5.9			
31	A	0.956				5.9			
	B	0.956				6.1			
32	A	0.956	1.58*	0.265	0.61	8.1		0.029	0.207
	B	0.956	1.72*	0.284	0.56	7.0		0.031	0.184
	C	0.956	1.75	0.291	0.55	6.2	1000	0.030	0.178
33	A	0.956	1.75	0.284	0.55	6.2	640	0.029	0.181
	B	0.956	1.82*	0.306	0.53	6.3		0.032	0.167
	C	0.956	1.87*	0.312	0.51	6.1	450	0.033	0.161
	D	0.956	1.75*	0.303	0.55	4.1	400	0.025	0.175
34	A	0.956	1.84	0.320	0.52	4.2	220	0.027	0.162
	B	0.956	1.73	0.314	0.55	5.1	332	0.028	0.174
	C	0.956				5.8			
	D	0.956	1.70	0.310	0.56	5.2	500	0.028	0.178
35	A	0.956				5.1	290		
	B	0.956				5.1	260		
	C	0.956				4.9	230		
	D	0.956				6.1	240		

* Only Bellevue Bend used to determine cross-sectional areas.

Manawa Bend

17. Initial model studies concentrated on attempts to increase the width of the navigation channel in Manawa Bend by utilizing a series of low elevation underwater sills extending from the concave bank. All test sills were constructed to an elevation 3 feet below normal navigation depths. Initially 200 foot sills were placed perpendicular to the concave bank at a horizontal spacing of 900 feet. Initial tests revealed that this spacing was too great, and the structures had little influence on the channel cross sections. One consistent problem noted with these structures was the large scour holes that developed on the upstream side of the sills. Generally, deposits accumulated on the downstream side of sills to an elevation slightly below the crest elevation. This effect was quite localized and did not extend very far downstream.

18. In subsequent tests, the horizontal spacing of the sills was reduced to 600 feet. This caused bed material to fill to the crest of the sills on the downstream side, but considerable scour still existed along the upstream side. In some instances, the scour began at the intersection of the structure and revetment and proceeded around the end of the sill creating a very undesirable channel. The scour appeared to become progressively greater in the downstream direction due to the decreasing radius of curvature. The sills were lengthened in an attempt to overcome the scour around the ends of the sills, but severe scour persisted upstream of the structures. Accretion continued to develop below the test structures but only extended a short distance downstream. Figure 8 is a photograph of the model bed of lower Manawa Bend at the completion of one of the tests in which the low elevation sills were studied. The horizontal spacing of the sills shown in this photograph represents 600 feet. The crest elevation of these structures was 12 feet below the normal water surface elevation. The flow in the model is from the bottom to the top of the photo. The lower downstream portion of the model basin shown in this photograph represents Bellevue Bend.

19. Previous studies at the Mead Hydraulic Laboratory had indicated that water passing over a sill tends to leave at right angles to the sill crest. Using this characteristic, tests were run in which the sills were oriented 15° upstream, to encourage additional flow along the inside of the bend. Severe scour upstream of the sills was still noted although it was less than that observed when the sills were placed perpendicular to the bank. Channel cross sections at the completion of these tests showed minor improvements to the navigation channel but the general performance of the structures was quite inconsistent. Plates 5 and 6 (Model Tests 20a and 20e) illustrate the channel that existed in Manawa Bend at the completion of one of the model tests in which these low elevation sills were tested.

Figure 8 - Photograph of Model Bed at Completion of Test Using low elevation concave bank sills.

20. Another attempt to widen the navigation channel was through the use of additional bank roughness along the concave bank of Manawa Bend. This was accomplished by placing short spurs of rock on top of the previously tested low elevation sills. These spurs extended into the flow a distance of 25 feet at the water surface and sloped down to the underwater sill at the normal angle of repose. It was felt that the additional bank roughness developed by these structures would cause the centroid of flow to be located a greater distance from the left bank, and create a wider channel. The result of these tests indicated that the fillets influenced the channel dimensions, and a general widening of the navigation portion of the channel did occur. However, the increased turbulence in the vicinity of the fillets would possibly create a navigation hazard along the outside of the bend. These combination low elevation sills and fillets had virtually no effect on the channel dimensions thru the crossing and into upper Bellevue Bend.

21. Attempts to widen the navigation channel in Manawa Bend also considered the use of a very irregular saw tooth shape bank roughness. Low elevation concave bank sills were used in conjunction with this test series and the results paralleled those found in previous studies. The channel did not respond to the additional roughness until extreme measures were taken, and the increased turbulance again resulted in an undesirable navigation condition.

Manawa to Bellevue Crossing

22. Model tests on improving the crossing between Manawa and Bellevue Bends centered on altering both the position and length of the crossing. Changes in the crossing usually influenced conditions in Bellevue Bend, therefore, the crossing and Bellevue Bend studies were combined, and are presented in the discussion of Bellevue Bend tests.

Bellevue Bend Tests

23. The very short abrupt crossing between Manawa and Bellevue Bends and the deep narrow channel that develops in the upper part of Bellevue Bend can be seen on Plates 1 and 3. Attempts to improve the crossing and upper Bellevue Bend included minor reorientation of Revetment 648.45, minor realignments of the upper portion of the bend and reorientation of the crossing, and a major realignment of the bend.

24. Relocation of the crossing thru the use of six "L" head structures is demonstrated by test 22b presented on plate 4. Initial tests utilized the "L" type structures and the left bank longitudinal sill shown on this drawing. The sill was constructed 3 feet below the normal water surface elevation to allow a small percentage of the flow to pass to the back side. This encouraged material to deposit behind it and the structure appeared to attract flow during the initial part of the test run. As the test progressed however, large accretions developed adjacent to the structure as shown by the bed map of test 22b. The water that passed to the back side of the longitudinal dike accumulated in the downstream direction to the extent that sufficient flow was available to scour a sizeable channel. The development of this secondary channel was arrested by the placement of low sills extending from the left bank out to the longitudinal sill. This test and other tests using similar layouts resulted in virtually no widening of the navigation channel in Bellevue Bend, however a minor change in the location of the crossing resulted in an improved sailing line. This system was not considered a feasible prototype solution because of the extensive construction requirements and its relative ineffectiveness.

25. The results of test 29b presented on plate 4 demonstrates an alignment similar to that used in test 22b except for the absence of the left bank longitudinal sill. No changes were made in orientation of the existing left bank dikes. The bankline at the upstream limits of Bellevue Bend was moved 200 feet toward the left bank so that the remaining channel width was 400 feet. The resulting navigation channel appeared satisfactory, however, the confinement resulted in extremely high velocities. The alignment used in both tests 22b and 29b resulted in an improved crossing but the downstream channel was still extremely narrow.

26. The maps shown on plates 5 and 6 show the alignment for a series of tests in which the channel in upper Bellevue Bend was moved toward the left and the location of the crossing moved upstream. Model test 20a presented on plate 5 used a completely reveted right bank extending 2400 feet upstream of the existing revetment. At the upstream limits of the existing right bank revetment, the channel was moved 360 feet riverward. The left bank revetment was extended downstream from existing revetment 648.45 leaving a 575 foot channel throughout most of the remaining reach except at the extreme upstream limits of the reach, the channel width was slightly less than this.

27. This alignment reduced the tight spiral or hook that presently exists in the downstream end of the crossing. Velocities measured in Bellevue Bend at the completion of the test showed a more desirable distribution of flow, with the highest velocities moved away from the outside of the bend. Cross-sections did not show a corresponding improvement, and a deep narrow channel along the right bank revetment was still evident. The bed map for model test 20a presented on plate 5 shows the accretion that developed near the left revetment in Bellevue Bend and the resulting narrow channel.

28. The results of tests 20b and 20e presented on plates 5 and 6 illustrate similar results. The first of these used the same right bank revetment but the left bank revetment was removed and replaced by the usual dikes. The number and spacing of the dikes used in test 20b is presented on plate 5. The channel width remained at 575 feet for this test. This test also resulted in a shorter more controlled crossing and improved alignment into Bellevue Bend. A confined channel again resulted below the crossing due to the development of a left bank point bar.

29. Attempts to widen the navigation channel were made by creating a rough boundary along the outside of the bend. This was accomplished by replacing the right bank revetment used in tests 20a and b with a series of "L" shaped dikes. The dikes were 500' long with 250 feet openings between the structures. The increased bank roughness and resulting turbulence along the bank should have assisted in developing a wider navigation channel, however only minor improvements were noted as a result of this change. Subsequent tests were made using shortened slightly angled "L" dikes with increased openings between structures as shown by test 20e on plate 6. The slight change in the angle of the "L" dikes did not significantly alter the shape of the navigation channel in Bellevue Bend.

30. Test 20e utilized underwater sills placed perpendicular to the "L" structures and constructed 12 feet below the normal water surface. The structures were successful in developing an accretion

immediately downstream of the sills. However, severe scour developed on the upstream side of the sills, and only local improvements were noted in the navigation channel. A deep narrow channel again existed immediately downstream of the structures as shown on the model study bed map.

31. Tests were also conducted using a longitudinal vane dike. This structure began at the crossing, extended throughout most of Bellevue Bend (test 31b), and was placed so that a 400 foot channel remained between the structure and the right bank revetment. The position of the extreme upstream limit of this dike was modified between tests to permit varying amounts of flow thru each of the two channels. The bed map on plate 6 shows the channel that existed when the flow was evenly divided in each of the channels. Most of the tests with this structure arrangement resulted in a deep, narrow channel on both sides of the structure. The tests showed that the majority of the flow must be confined to one of the sections to obtain a satisfactory navigation channel. However, this resulted in increased channel velocities and in addition, maneuvering a tow into either of the two channels would be extremely difficult.

32. A major realignment of the crossing and Bellevue Bend was also investigated as demonstrated by test 34a on Plate 7 which shows both the existing and new alignments. For this test the structures were moved 800 feet toward the left at the upstream limits of the reach, 1000 feet to the left near dike 647.8 and merged with the existing revetment downstream of dike 647.1.

33. Major channel improvements were noted as a result of this realignment. The tight spiral curve at the downstream end of Manawa Bend was eliminated which lengthened the crossing between Manawa and Bellevue Bend and created a substantially wider channel throughout the length of Bellevue Bend.

34. Many other systems of structures similar to the tests presented on plates 3 thru 7 were investigated and comparable results were observed. The studies presented in this report are representative of the various systems investigated.

CONCLUSIONS

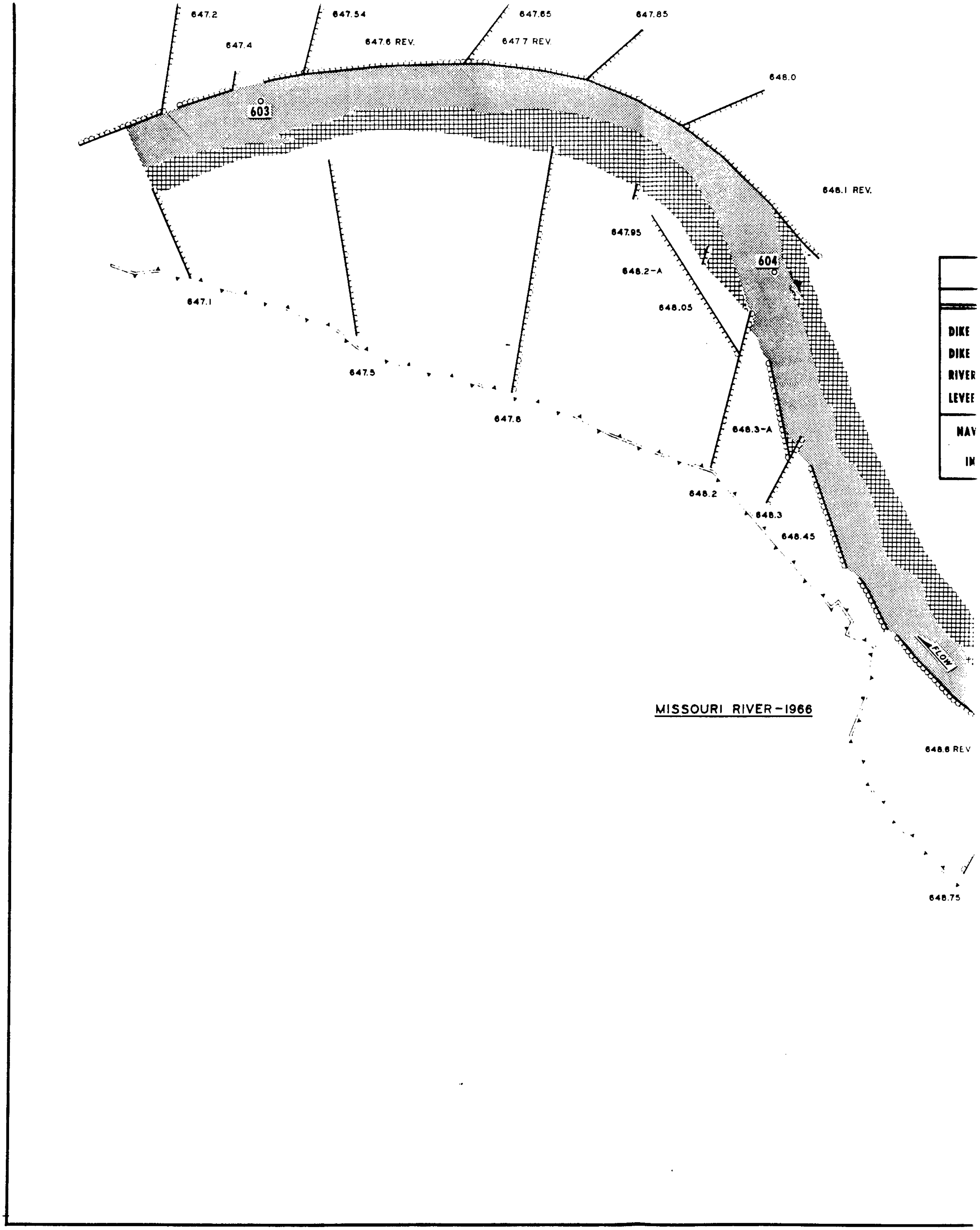
35. The effects of low elevation concave bank sills on the navigation channel are very localized. Severe scour holes consistently developed upstream of the structures and a limited amount of accretion developed downstream of the sills.

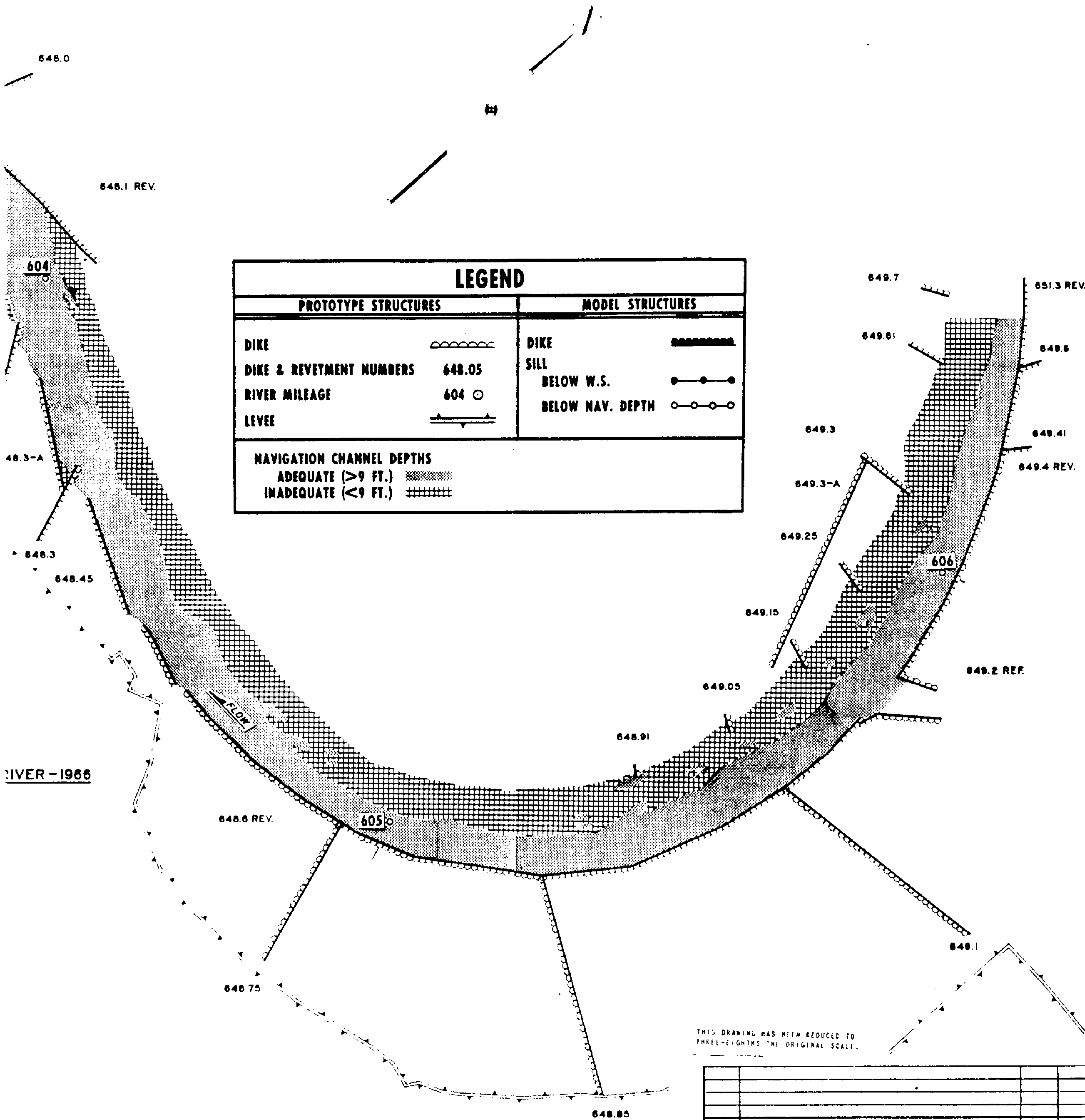
36. The channel dimensions are significantly influenced by the radius of curvature of the bend. Widening the channel in a sharp bend can be accomplished by providing additional roughness on the bed or

banks of the stream. The model demonstrated the extreme roughness would be required to significantly improve the channel thru Manawa Bend. The corresponding increase in turbulance would pose an extreme navigation hazard.

37. A minor realignment of the crossing and upper Bellevue Bend will improve traffic conditions thru the crossing. No improvement in the channel dimensions were noted as a result of this change.

38. A major realignment similar to the one presented on plate 7 demonstrated measurable improvements in the navigation channel. The short abrupt crossing and confined channel throughout Bellevue Bend were eliminated, however, no improvements were noted in the channel geometry in Manawa Bend. No satisfactory solution was found for eliminating the narrow channel through this reach.


647.2
647.54
647.65
647.85
647.4
647.6 REV.
647.7 REV.
648.0
603
648.1 REV.
647.95
604
648.2-A
647.1
648.05
647.5
647.8
648.3-A
648.2
648.3
648.45
FLOW
MISSOURI RIVER-1966
648.6 REV
648.75
DIKE
DIKE
RIVER



THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY: D J S
DRAWN BY: R C C
CHECKED BY: W C K
SUBMITTED BY: L. S. Hinshaw, CHIEF HYDRO BED SECTION
APPROVED: J. J. Slezak, CHIEF HYDRO ENGRG BRANCH

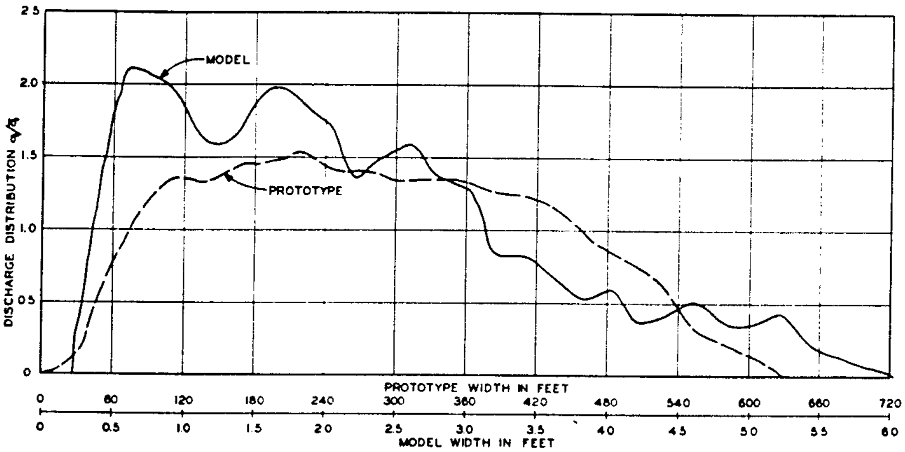
MISSOURI RIVER DESIGN STUDY
MANAWA - BELLEVUE MODEL
1966 RIVER BED MAP
OF STUDY REACH

APPROVED: R. G. Burnett, CHIEF ENGINEERING DIVISION
DATE: FEB 1972
APPROVED: B. P. Pendergrass, COL. C. E. DISTRICT ENGINEER
SCALE AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

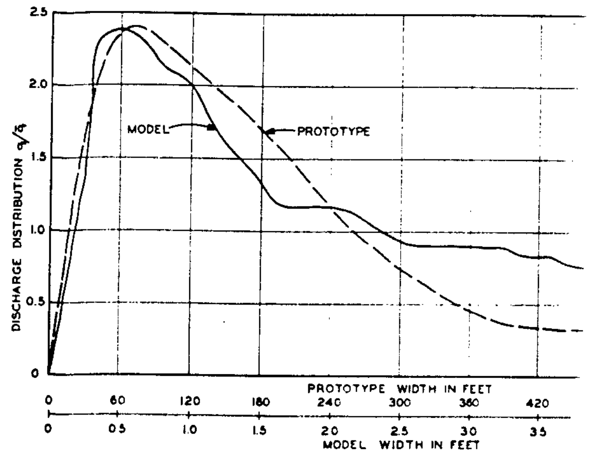
THIS PLAN ACCOMPANIES CONTRACT NO.
MODIFICATION NO.

SAFETY PAYS

PLATE 1

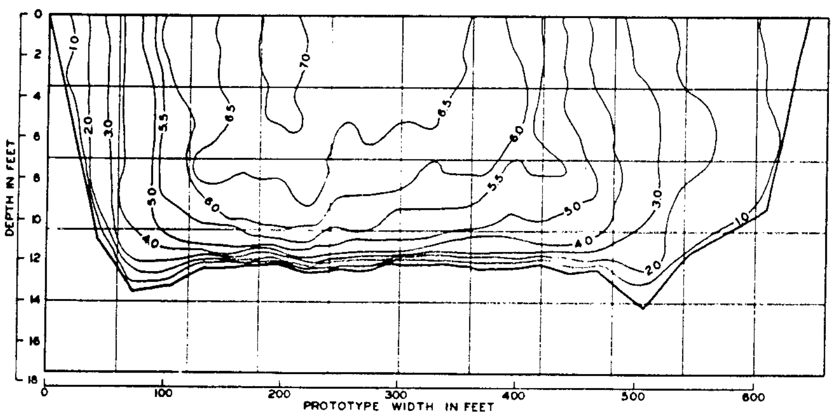


RIVER MILE 604.08

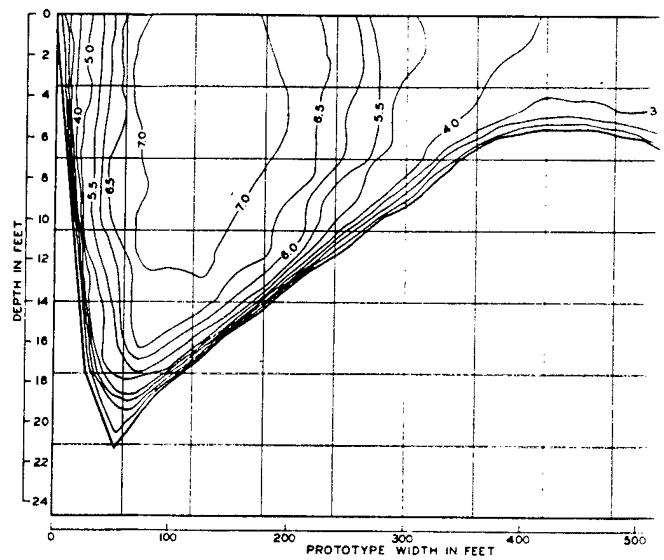


RIVER MILE 605.18

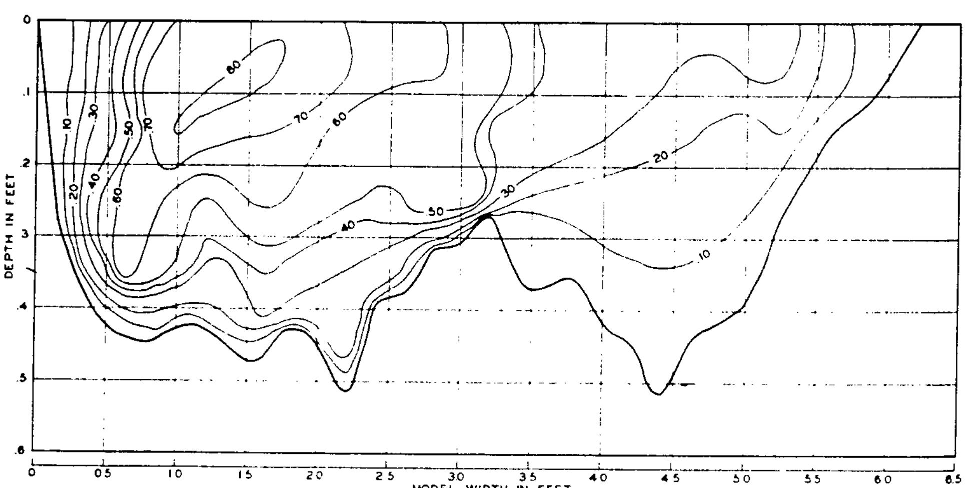
DISCHARGE DISTRIBUTION



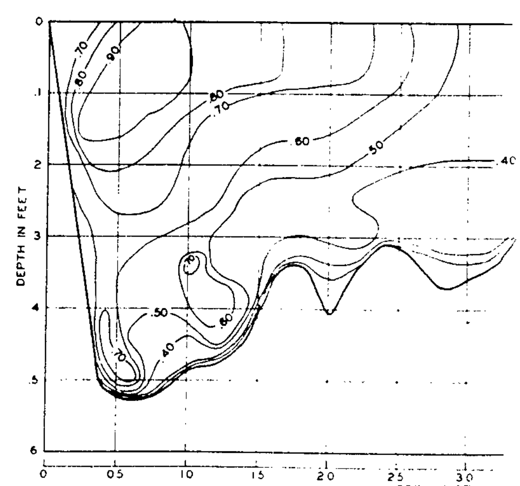
RIVER MILE 604.08



RIVER MILE 605.18

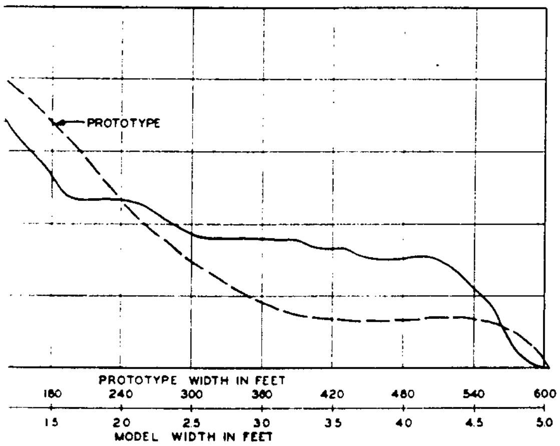


RIVER MILE 604.08

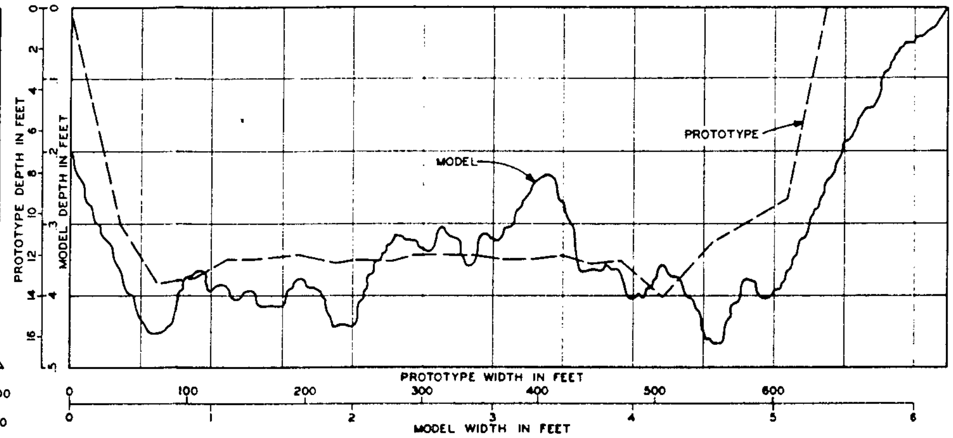


RIVER MILE 6

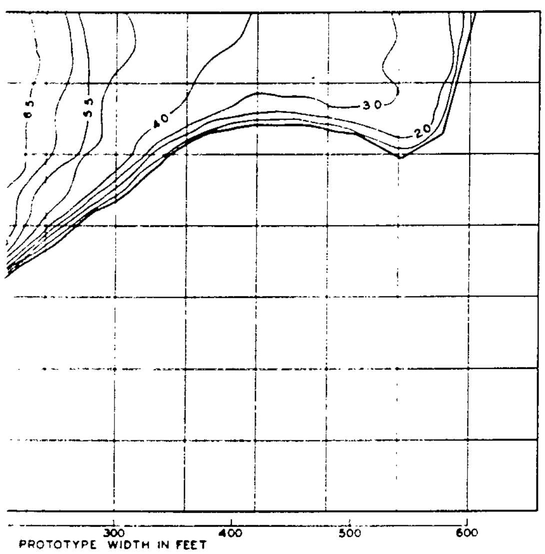
VELOCITY DISTRIBUTION



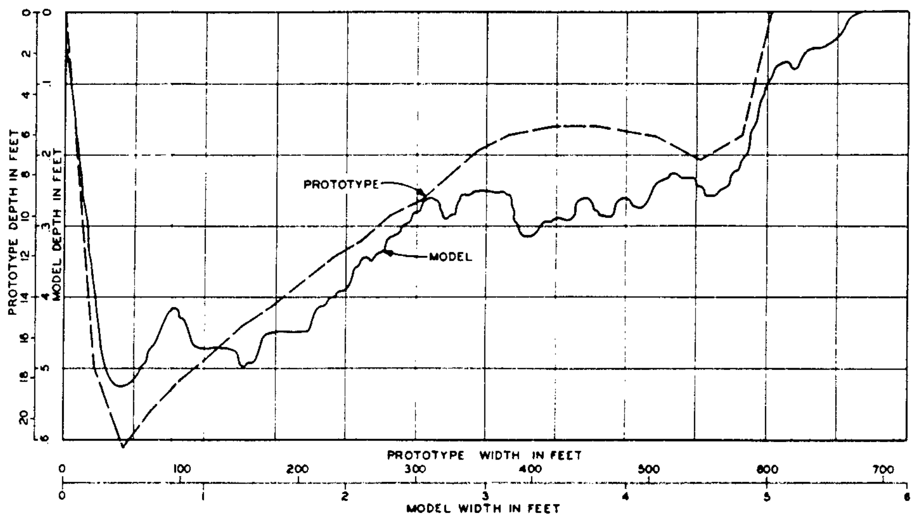
RIVER MILE 605.18



RIVER MILE 604.08

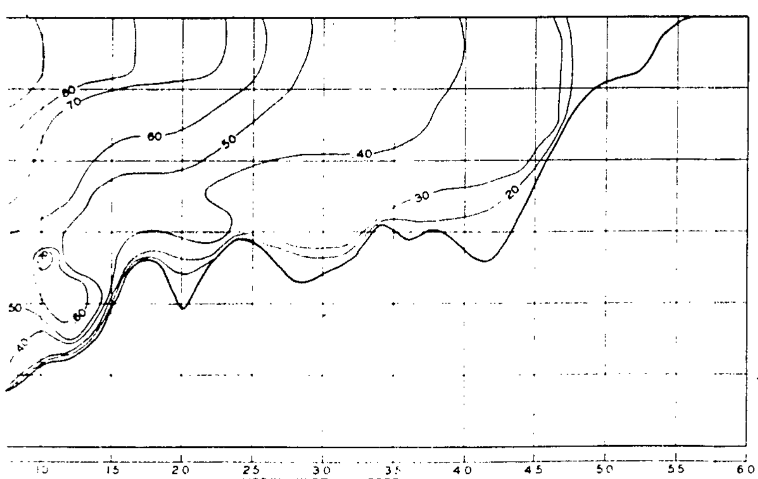


RIVER MILE 605.18



RIVER MILE 605.18

CROSS SECTIONS



RIVER MILE 605.18

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPR'D
	REVISIONS		

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY: D J S
DRAWN BY: J L C
CHECKED BY: W C F
SUBMITTED BY: R J Hoeden — CHIEF HYDRO SED SECTION
APPROVED: — CHIEF HYDRO ENGR. BRANCH
APPROVED: R. Burnett — CHIEF ENGINEERING DIVISION
APPROVED: B. J. Pendergrass — COL. C. E. DISTRICT ENGINEER

MISSOURI RIVER DESIGN STUDY

MANAWA - BELLEVUE MODEL

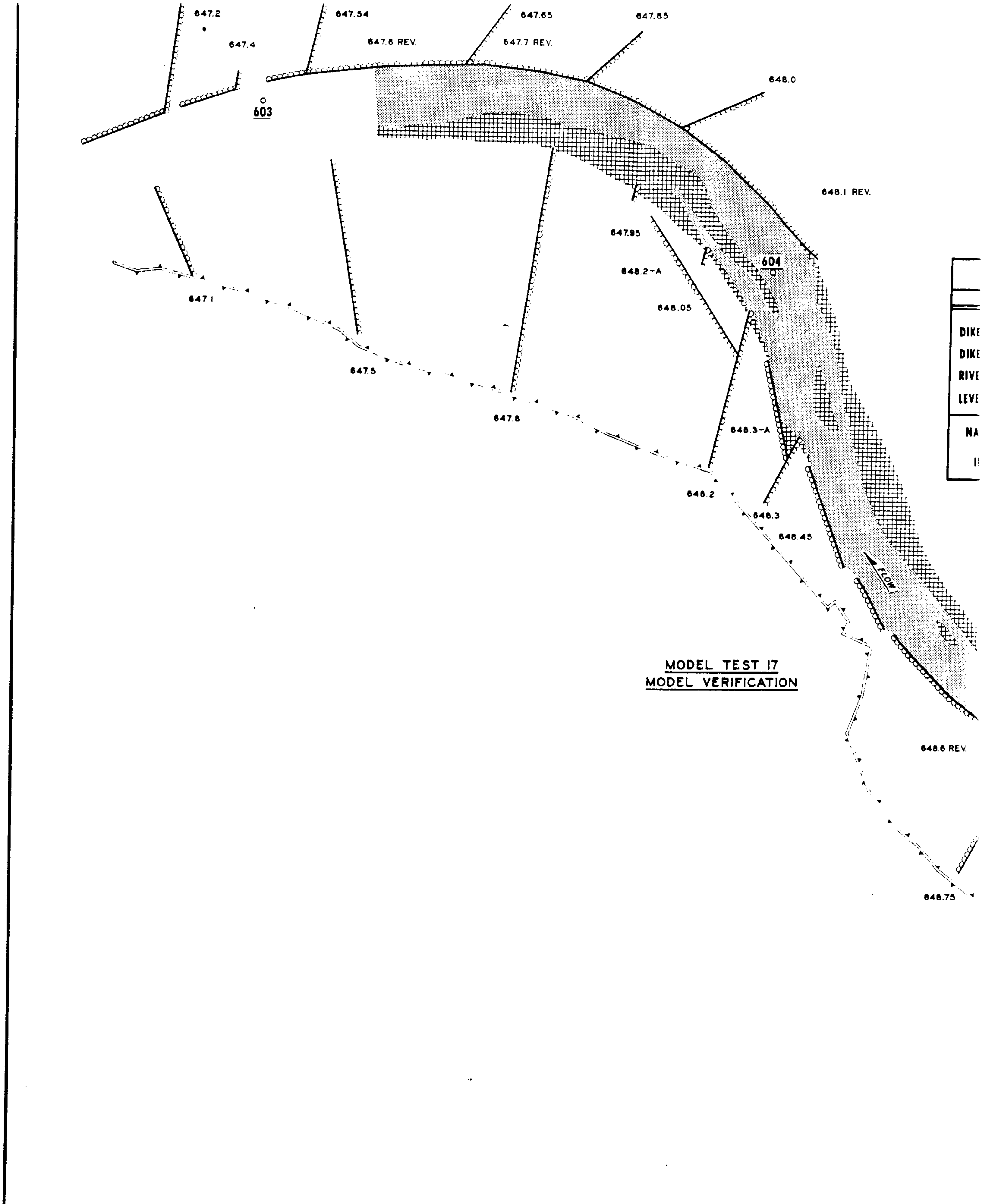
MODEL VERIFICATION

DATE: FEB 1972
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

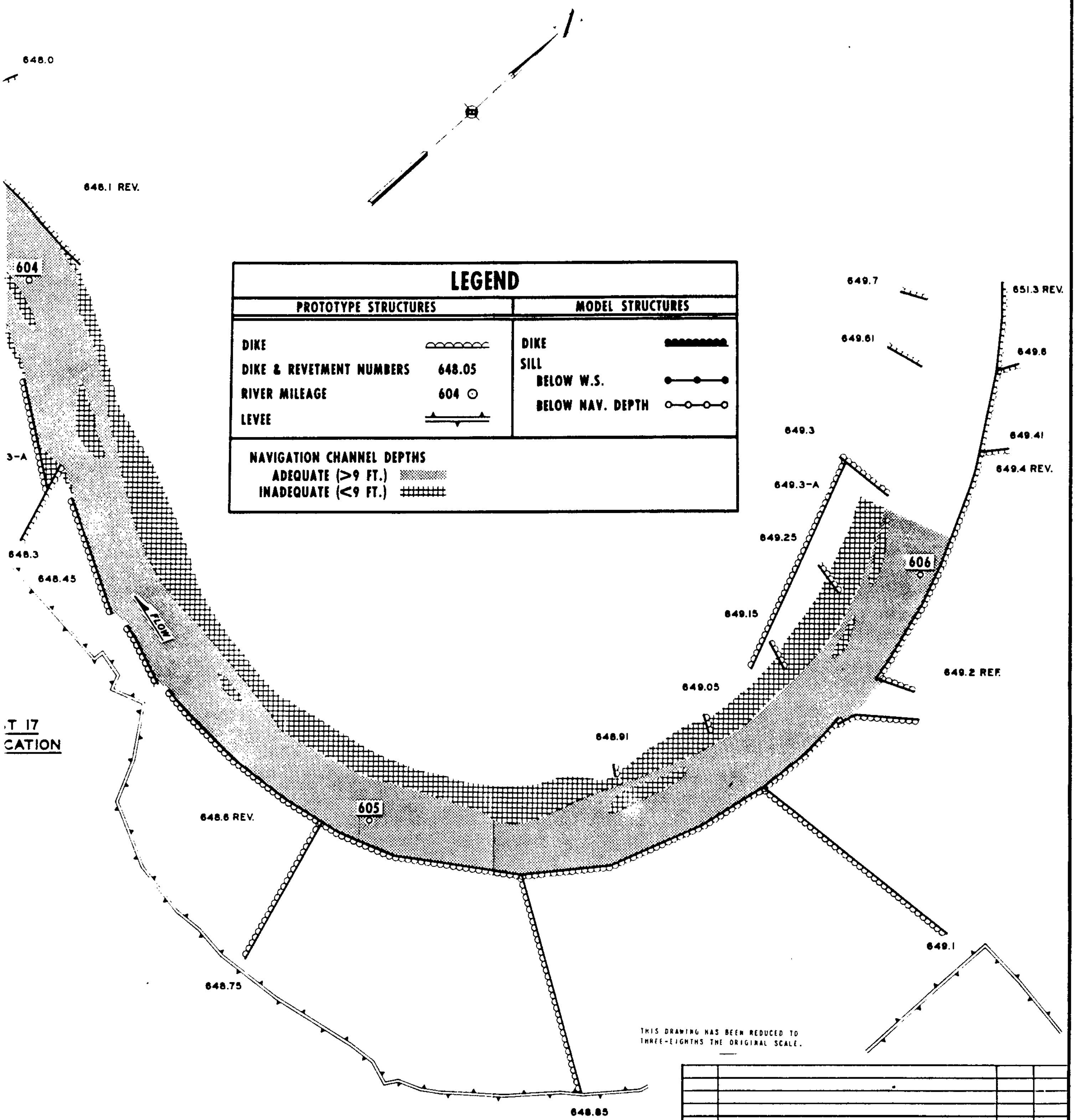
THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

PLATE 2

(2)



MODEL TEST 17
MODEL VERIFICATION



DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY: D J B
DRAWN BY: R G C
CHECKED BY: W C H
SUBMITTED BY: CHIEF HYDRO SED SECTION
APPROVED: CHIEF HYDRO. ENGRG. BRANCH
APPROVED: B. P. Pendergrass
APPROVED:

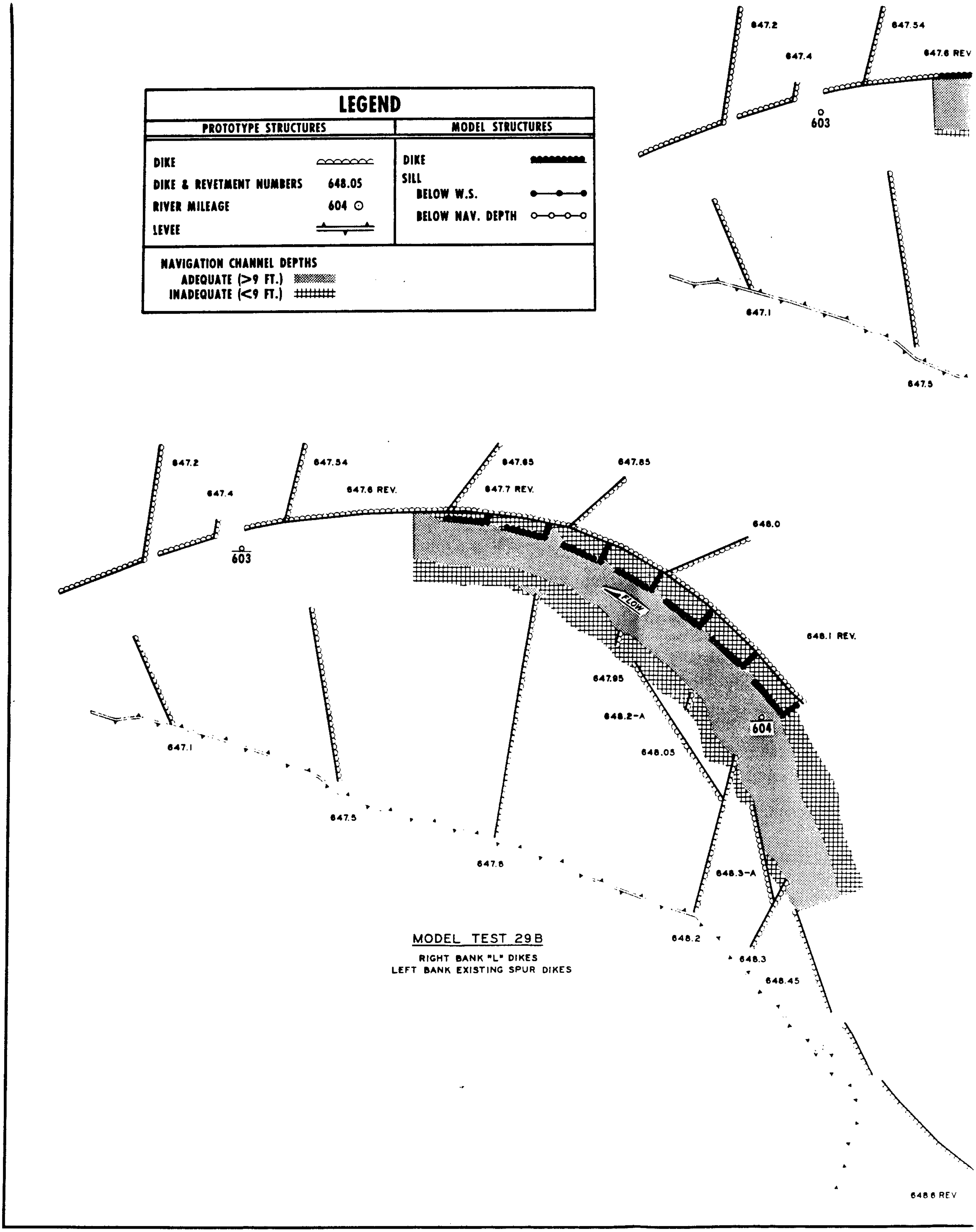
MISSOURI RIVER DESIGN STUDY
MANAWA – BELLEVUE MODEL
MODEL BED MAP OF STUDY REACH
VERIFICATION TEST

DATE: FEB 1972
SCALE: AS SHOWN
DRAWING NUMBER
SHEET

SAFETY PAYS

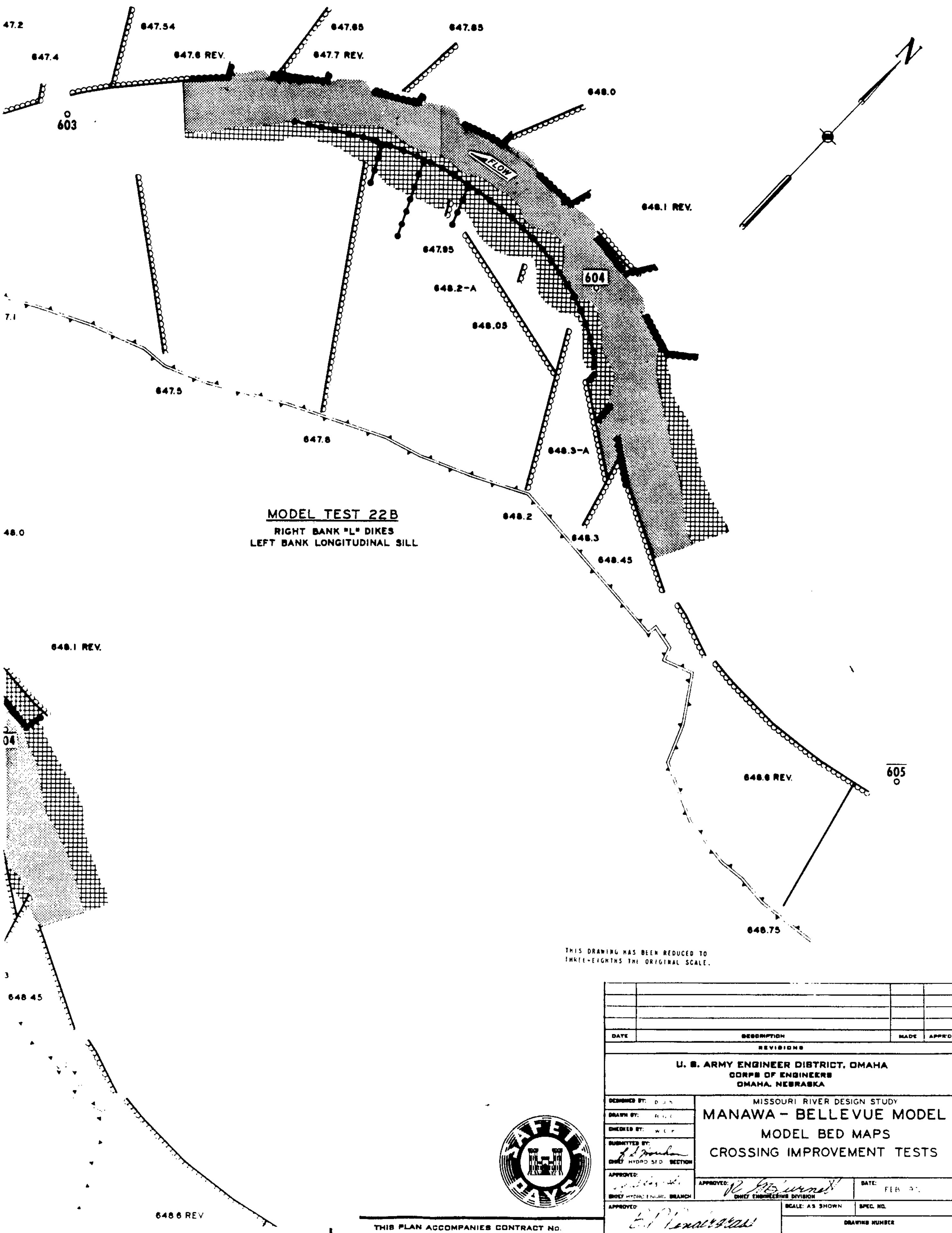
THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

PLATE 3



MODEL TEST 29B

RIGHT BANK "L" DIKES
LEFT BANK EXISTING SPUR DIKES



MODEL TEST 22B

RIGHT BANK "L" DIKES
LEFT BANK LONGITUDINAL SILL

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY:
DRAWN BY:
CHECKED BY:
SUBMITTED BY: CHIEF HYDRO SED. SECTION
APPROVED: CHIEF HYDRO ENGIN. BRANCH
APPROVED: CHIEF ENGINEERING DIVISION
APPROVED: COL. C. E. DISTRICT ENGINEER

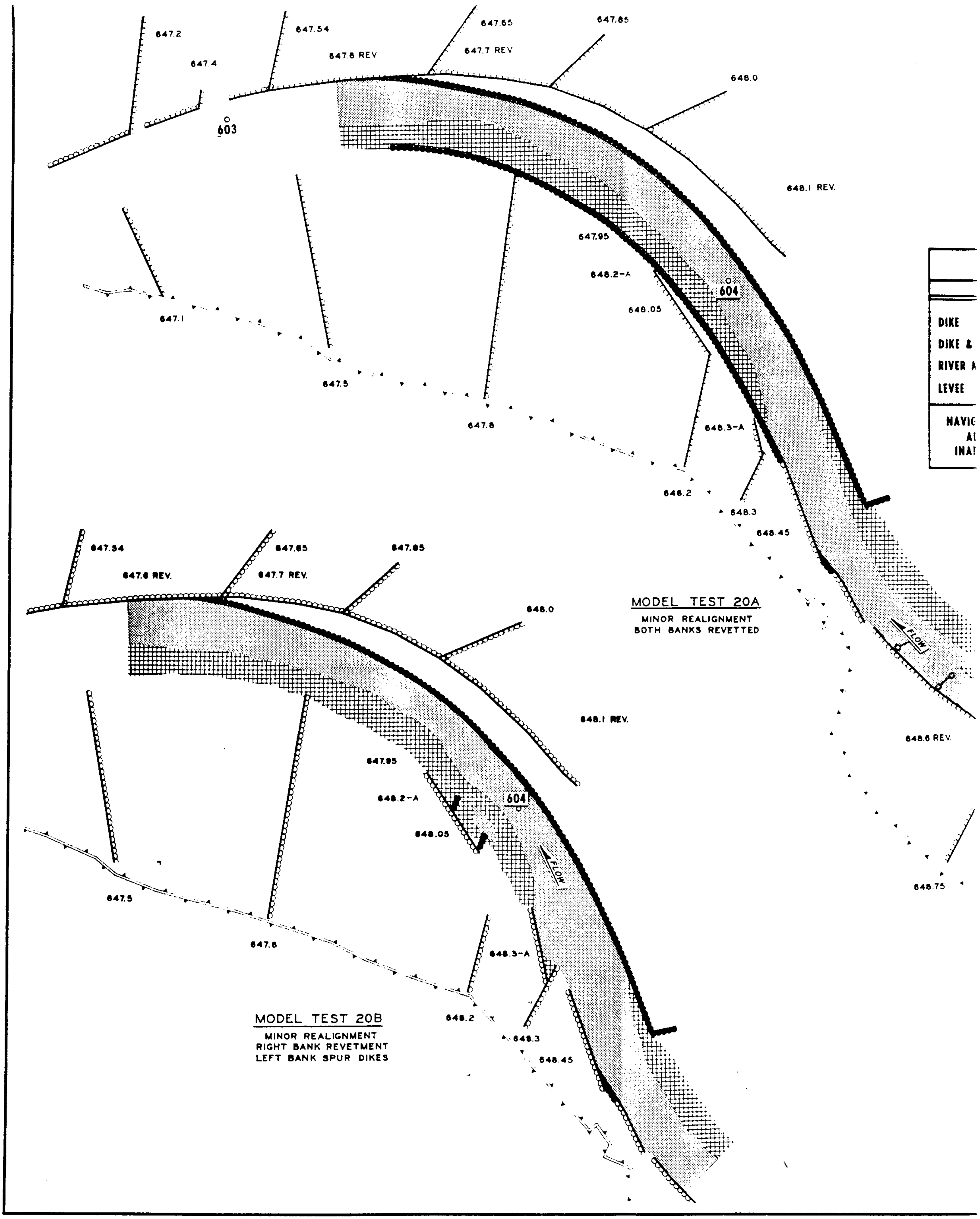
MISSOURI RIVER DESIGN STUDY
MANAWA – BELLEVUE MODEL
MODEL BED MAPS
CROSSING IMPROVEMENT TESTS

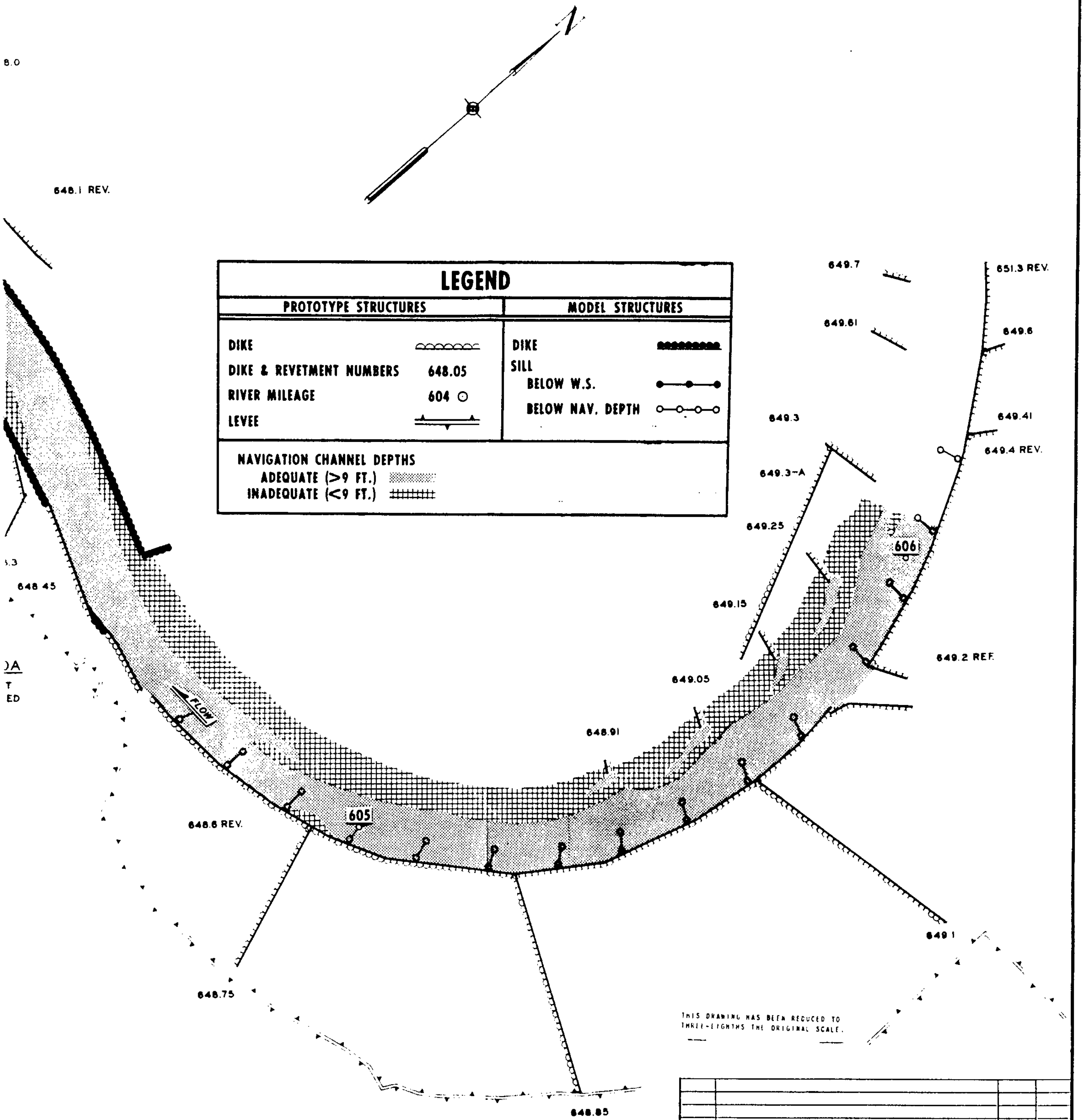
DATE: FEB
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

2

PLATE 4


647.2
647.54
647.65
647.85
647.4
647.6 REV
647.7 REV
648.0
603
648.1 REV.
647.95
648.2-A
604
648.05
DIKE
DIKE &
RIVER
LEVEE
NAVIG
647.1
647.5
647.8
648.3-A
648.2
648.3
648.45
MODEL TEST 20A
MINOR REALIGNMENT
BOTH BANKS REVETTED
FLOW
648.6 REV.
648.75
647.54
647.65
647.85
647.6 REV.
647.7 REV.
648.0
648.1 REV.
647.95
648.2-A
604
648.05
FLOW
647.5
647.8
648.3-A
648.2
648.3
648.45
MODEL TEST 20B
MINOR REALIGNMENT
RIGHT BANK REVETMENT
LEFT BANK SPUR DIKES



DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY: D J S
DRAWN BY: J L C
CHECKED BY: W C H
SUBMITTED BY:
CHIEF HYDRO SED SECTION
APPROVED:
CHIEF HYDRO ENGRG BRANCH
APPROVED:
COL. C. E. DISTRICT ENGINEER

MISSOURI RIVER DESIGN STUDY
MANAWA – BELLEVUE MODEL
MODEL BED MAPS
MINOR REALIGNMENT

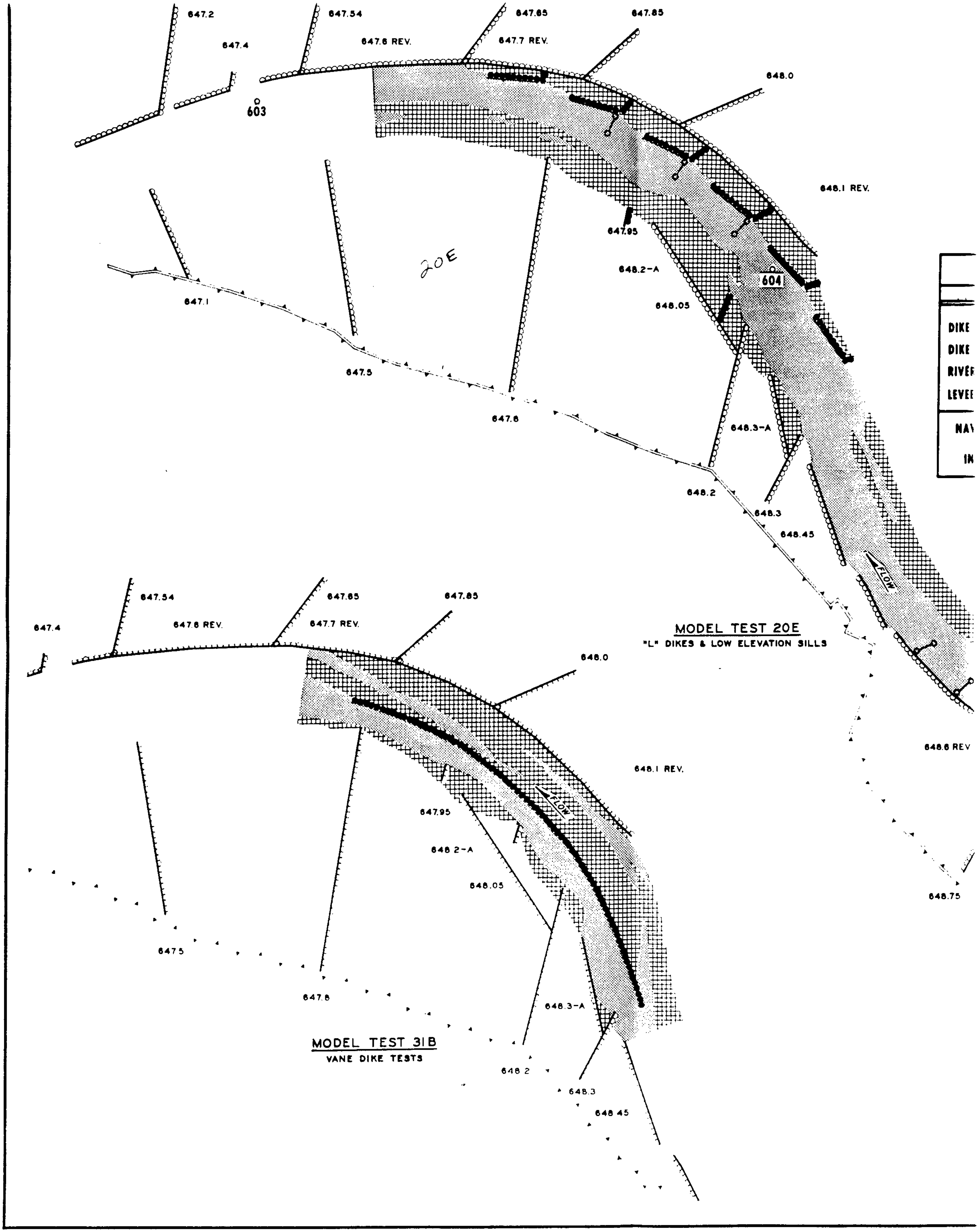
APPROVED: CHIEF ENGINEERING DIVISION
DATE: FEB 1972
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

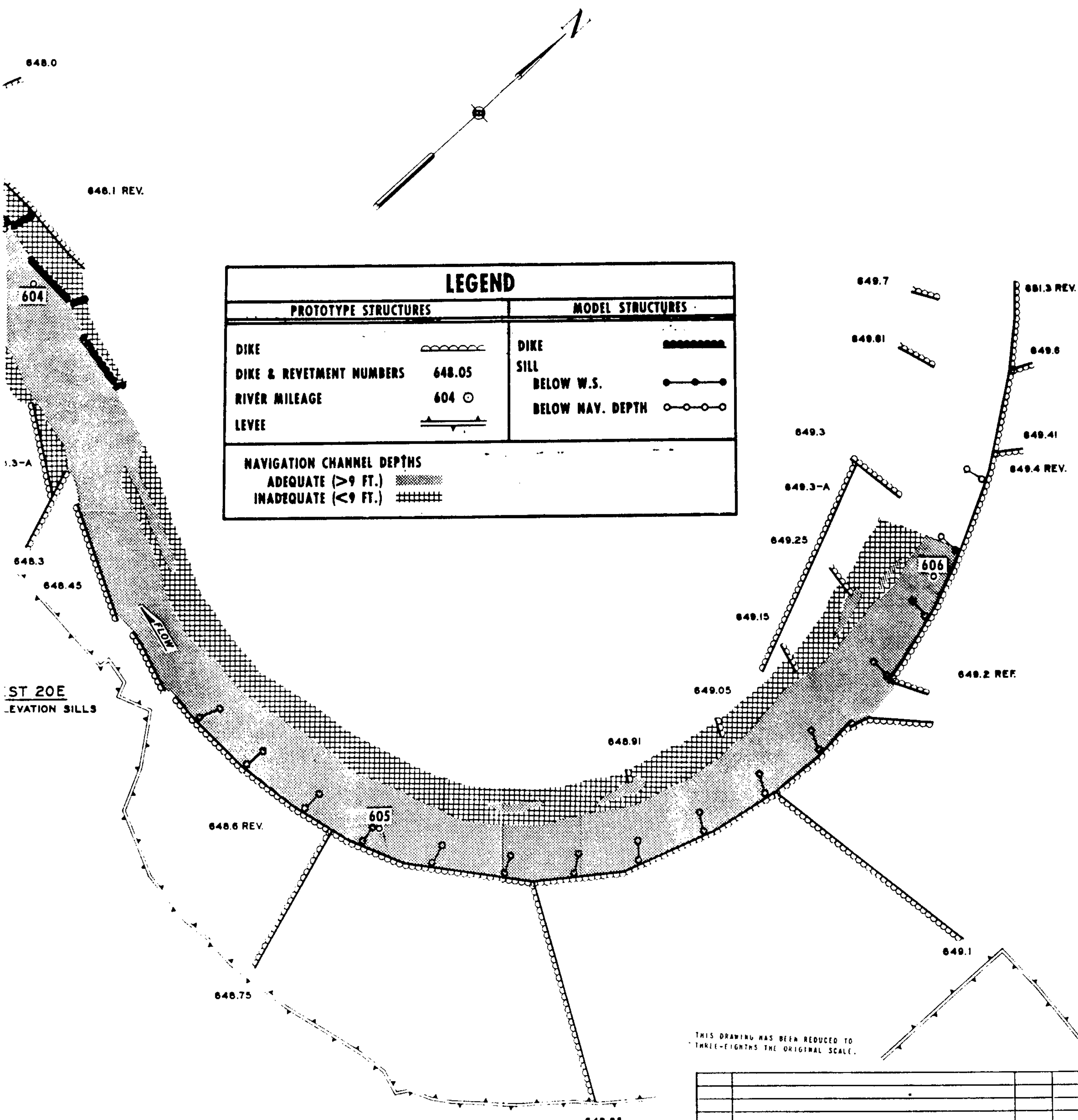
SAFETY PAYS

PLATE 5

(2)


647.2
647.54
647.65
647.85
647.4
647.6 REV.
647.7 REV.
603
648.0
20E
648.1 REV.
647.95
648.2-A
604
647.1
648.05
DIKE
DIKE
RIVER
LEVEE
647.5
647.6
648.3-A
648.2
648.3
648.45
FLOW
MODEL TEST 20E
"L" DIKES & LOW ELEVATION SILLS
647.54
647.65
647.85
647.4
647.6 REV.
647.7 REV.
648.0
648.6 REV
648.1 REV.
FLOW
647.95
648 2-A
648.05
648.75
647.5
647.6
648.3-A
MODEL TEST 31B
VANE DIKE TESTS
648 2
648.3
648 45

1



THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPR'D
	REVISIONS		

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

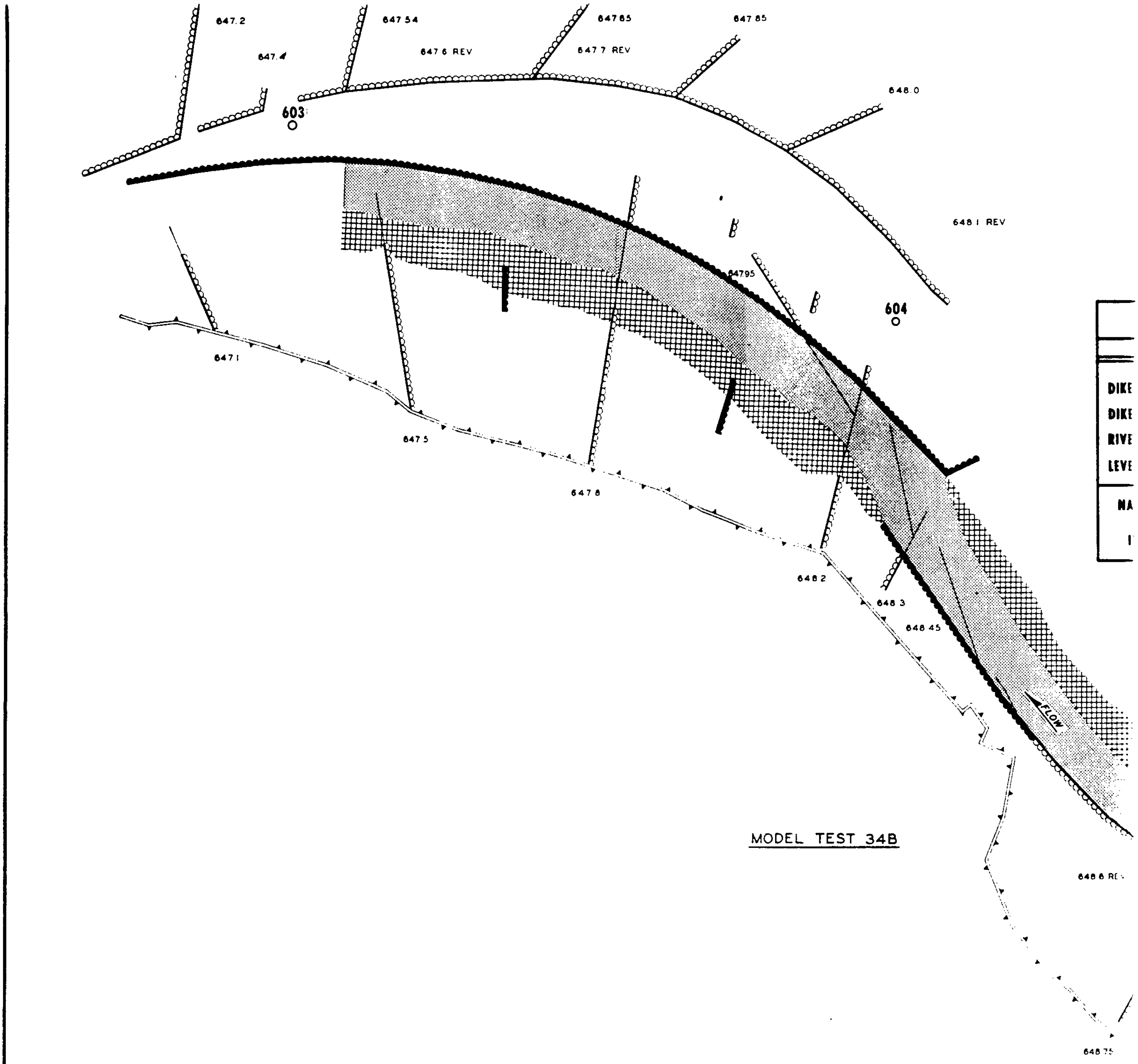
DESIGNED BY: D J S
DRAWN BY: R G C
CHECKED BY: W C H
SUBMITTED BY: CHIEF HYDRO BED SECTION
APPROVED: CHIEF HYDRO ENGRG BRANCH
APPROVED: CHIEF ENGINEERING DIVISION
APPROVED: B P Pendergrass, COL. C. E. DISTRICT ENGINEER

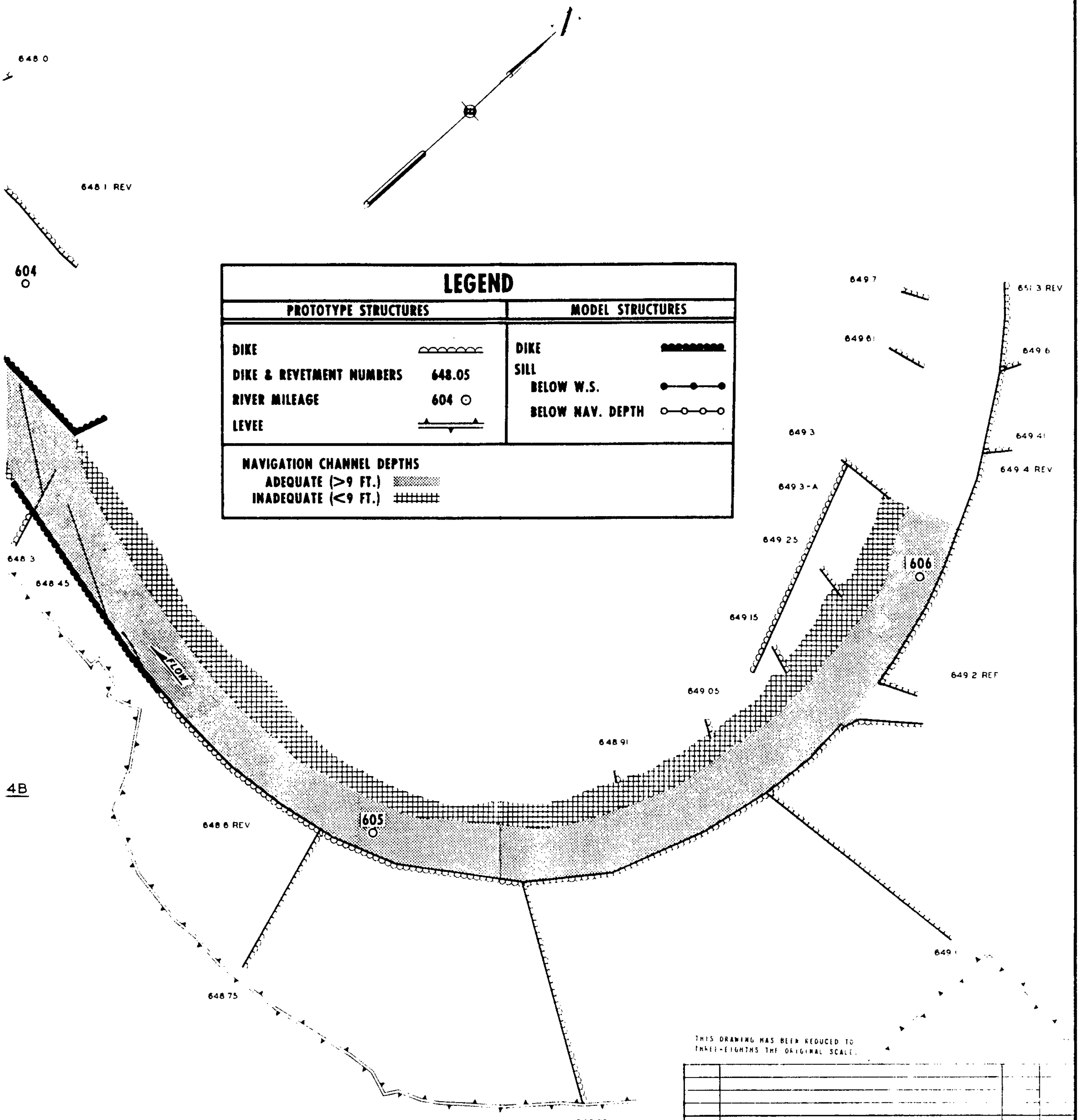
MISSOURI RIVER DESIGN STUDY
MANAWA - BELLEVUE MODEL
MODEL BED MAPS
MINOR REALIGNMENT AND
VANE DIKE TESTS

DATE: FEB 1972
SCALE: AS SHOWN
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT No.
MODIFICATION No.

PLATE 6


647.2
647.54
647.85
647.85
647.4
647.6 REV
647.7 REV
603
648.0
648.1 REV
647.95
604
DIKE
DIKE
RIVE
LEVE
647.1
647.5
647.8
648.2
648.3
648.45
FLOW
MODEL TEST 34B
648.75



THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

DATE	DESCRIPTION	MADE	APPR'D

REVISIONS

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

DESIGNED BY:
DRAWN BY:
TRACED BY
CHECKED BY:
SUBMITTED BY: CHIEF HYDRAULICS SECTION
APPROVED: CHIEF HYDRAULICS BRANCH
APPROVED: CHIEF ENGINEERING DIVISION
DATE
APPROVED: COL. C. E., DISTRICT ENGINEER

MISSOURI RIVER DESIGN STUDY
MANAWA - BELLEVUE MODEL
MAJOR REALIGNMENT
OF
BELLEVUE BEND

SCALE
SPEC. NO.
DRAWING NUMBER
SHEET

THIS PLAN ACCOMPANIES CONTRACT NO.
MODIFICATION NO.

PLATE 7

2